Washington State Department of Transportation

SR 3 MP 59.55 Unnamed Tributary to Hood Canal (996811): Preliminary Hydraulic Design Report

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ROLES AND RESPONSIBILITIES FOR THIS PRELIMINARY HYDRAULIC DESIGN

The roles and responsibilities of the key individuals in developing this Preliminary Hydraulic Design (PHD) are defined as follows for the Olympic Region GEC:

PHD Lead PE
Responsibility: Water Resources Professional Engineer in responsible charge of this Hydraulic Design Report, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices.

Authoring Firm PHD QC Reviewer(s)
Responsibility: Qualified independent individual(s) responsible for the detailed checking and reviewing of hydraulic and stream design documents prepared by the authoring firm, including all information, calculations, assumptions, modeling, professional judgment, and commitments contained in the main report and appendices. Before submittal to the GEC, the authoring Firm Quality Control (QC) Review shall be performed in accordance with the QC methods identified in the quality assurance document Technical Verification Form. The QC methods are defined in the Olympic Region GEC Quality Management Plan Section 5.3 and the Quality Management Plan Supplement developed specifically for Y-12554 Task AC.

Olympic Region GEC Fish Passage/Stream Design Advisor
Responsibility: Water Resources Professional Engineer providing mentorship, process oversight, quality check issue resolution, and recommendations in the approach to hydraulic analysis and design performed by the **PHD Lead PE**. Before submittal of draft deliverables from the GEC to either the PHD Lead or WSDOT Headquarters, the Olympic Region GEC Fish Passage/Stream Design Advisor will review and refine GEC comments and confirm GEC comment resolution by the **PHD Lead PE**.

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1 Introduction

To comply with United States et al. vs. Washington, et al. No. C70-9213 Subproceeding No. 01-1 dated March 29, 2013 (a federal permanent injunction requiring the State of Washington to correct fish barriers in Water Resource Inventory Areas [WRIAs] 1 through 23), the Washington State Department of Transportation (WSDOT) is proposing a project to provide fish passage at the State Route (SR) 3 crossing of the unnamed tributary (UNT) to Hood Canal at milepost (MP) 59.55 within WSDOT's Olympic region. The existing structure at that location has been identified as a fish barrier by the Washington Department of Fish and Wildlife (WDFW) and WSDOT Environmental Services Office (ESO) (site identifier [ID] 996811) and has an estimated 2,100 linear feet (LF) of habitat gain.

Per the federal injunction, and in order of preference, fish passage should be achieved by (1) avoiding the necessity for the roadway to cross the stream, (2) use of a full-span bridge, or (3) use of the stream simulation methodology. WSDOT is proposing to replace the existing crossing structure with a structure designed using the stream simulation methodology. This method was chosen because the stream is confined and has a bankfull width (BFW) of less than 15 feet (ft).

The crossing is located in Kitsap County, 1 mile southeast of Port Gamble, Washington, in WRIA 15. The highway runs in a north–south direction at this location and is about 450 feet from Hood Canal. The UNT to Hood Canal generally flows from east to west beginning approximately 2,500 LF upstream (US) of the SR 3 crossing (see Figure 1 for the vicinity map).

The proposed project will replace the existing 2-foot-diameter, circular, 120-foot-long reinforced concrete pipe (RCP) with a structure designed to accommodate a minimum hydraulic width of 15 feet. The proposed structure is designed to meet the requirements of the federal injunction using the stream simulation design criteria as described in the 2013 WDFW *Water Crossing Design Guidelines* (WCDG) (Barnard et al. 2013). This design also meets the requirements of the WSDOT *Hydraulics Manual* (WSDOT 2022a). Structure type is not being recommended by Headquarters (HQ) Hydraulics and will be determined by others at future design phases.

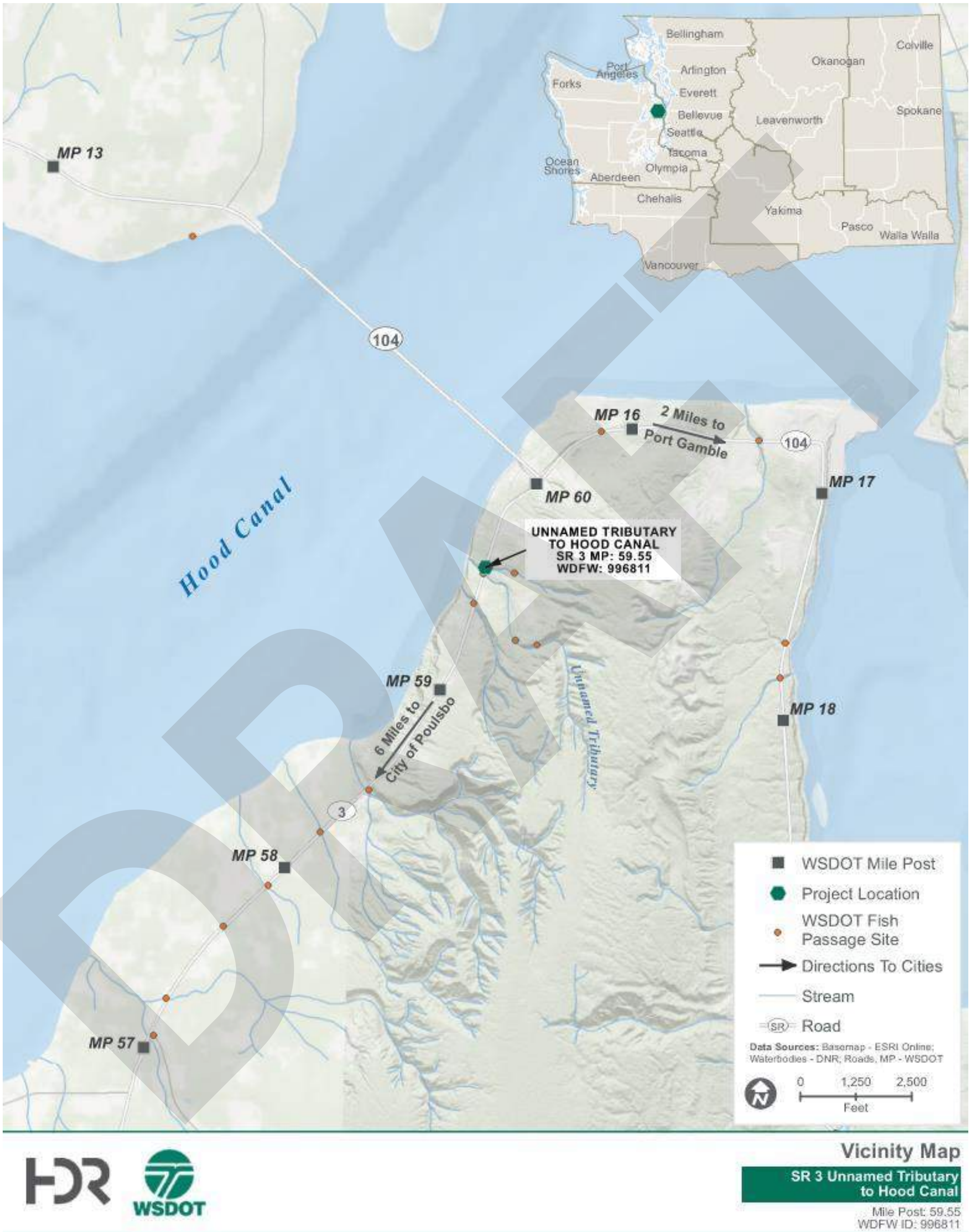

Figure 1: Vicinity map

2 Watershed and Site Assessment

The existing watershed was assessed in terms of land cover, geology, regulatory floodplains, fish presence, site observations, wildlife crossing priority, and geomorphology. This was performed using a site visit and desktop research with resources such as the United States Geological Survey (USGS), Federal Emergency Management Agency (FEMA), and WDFW, and past records like observations, maintenance, and fish passage evaluation.

2.1 Site Description

UNT to Hood Canal at SR 3 MP 59.55 was identified as a slope barrier to coho salmon, sea-run cutthroat trout, and resident trout. The slope of the existing culvert creates a passage barrier to fish moving upstream. Spawning habitat is lacking so the stream functions as a migratory corridor for juvenile fish of these species to move up into rearing habitat, particularly for overwintering before moving out into Hood Canal. The undersized culvert prevents natural stream processes including woody material and sediment transport. WDFW estimates that the crossing has a rating of 0 percent passability for active species. With restoration of the corridor, WDFW expects 2,100 feet of habitat gain (WDFW 2010).

WSDOT provided no maintenance records for this crossing, so no flooding history was included. No evidence of high water marks were observed from the site visit either. In correspondence with WSDOT, the crossing has not been identified as a chronic environmental deficiency or failing structure.

2.2 Watershed and Land Cover

The 0.1-square-mile basin delineated for UNT to Hood Canal is located east of the crossing of SR 3. The lowest point of the watershed is at an elevation of 50 feet at the culvert inlet. Following the flow path upstream for the next 3,500 horizontal feet, the watershed terrain slopes up from the culvert inlet until it reaches the top of the watershed at an approximate elevation of 380 feet. These elevations are based on the North American Vertical Datum of 1988 (NAVD88). The UNT to Hood Canal originates from the southern portion of the watershed and crosses a private culvert at WDFW site ID 996861 through NE Babcock Road at MP 0.18. Approximately 60 feet downstream (DS) of WDFW site ID 996811 the tributary joins with another UNT to Hood Canal flowing though WDFW site ID 991612. Downstream of the confluence, the tributary continues for approximately 450 feet before flowing into Hood Canal. Arc Hydro was used in combination with light detection and ranging (LiDAR) data obtained from the Washington State Department of Natural Resources (DNR) to delineate the basin. See Figure 2 for a watershed map of the area.

The historical land cover was analyzed based on historical aerial photographs ranging from 1951 to 2019 downloaded from USGS Earth Explorer. Based on the historical imagery, the basin is characterized by a dense forest that has been rotationally clear cut throughout the past 70 years.

The current land cover was classified using National Land Cover Database (NLCD) classifications. Based on the 2016 NLCD map (Figure 3) this basin is dominated by evergreen forest land cover, which covers 40.4 percent of the watershed. The next largest land cover classes in the watershed are mixed forest (23.9 percent), shrub/scrub land (16.7 percent), and deciduous forest (14.3 percent). Less than 10 percent of the watershed is made up of low-intensity development, herbaceous land cover, and developed open space. The distribution is shown in Table 1.

Table 1: Land cover

Land cover class	Basin coverage (percentage)
Deciduous forest	14.3
Developed, low intensity	2.2
Developed, open space	0.2
Evergreen forest	40.4
Herbaceous	2.3
Mixed forest	23.9
Shrub/scrub	16.7

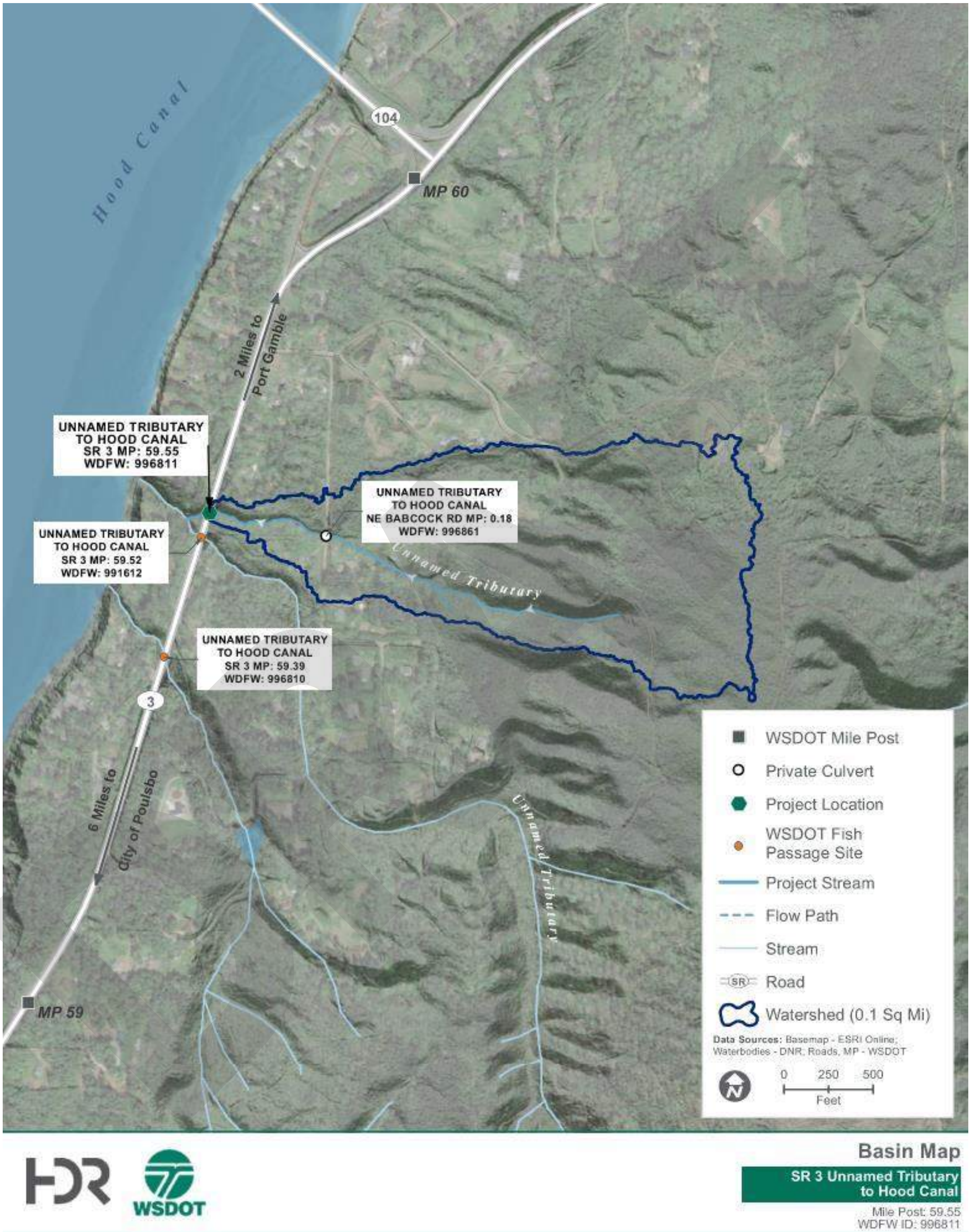

Figure 2: Watershed map

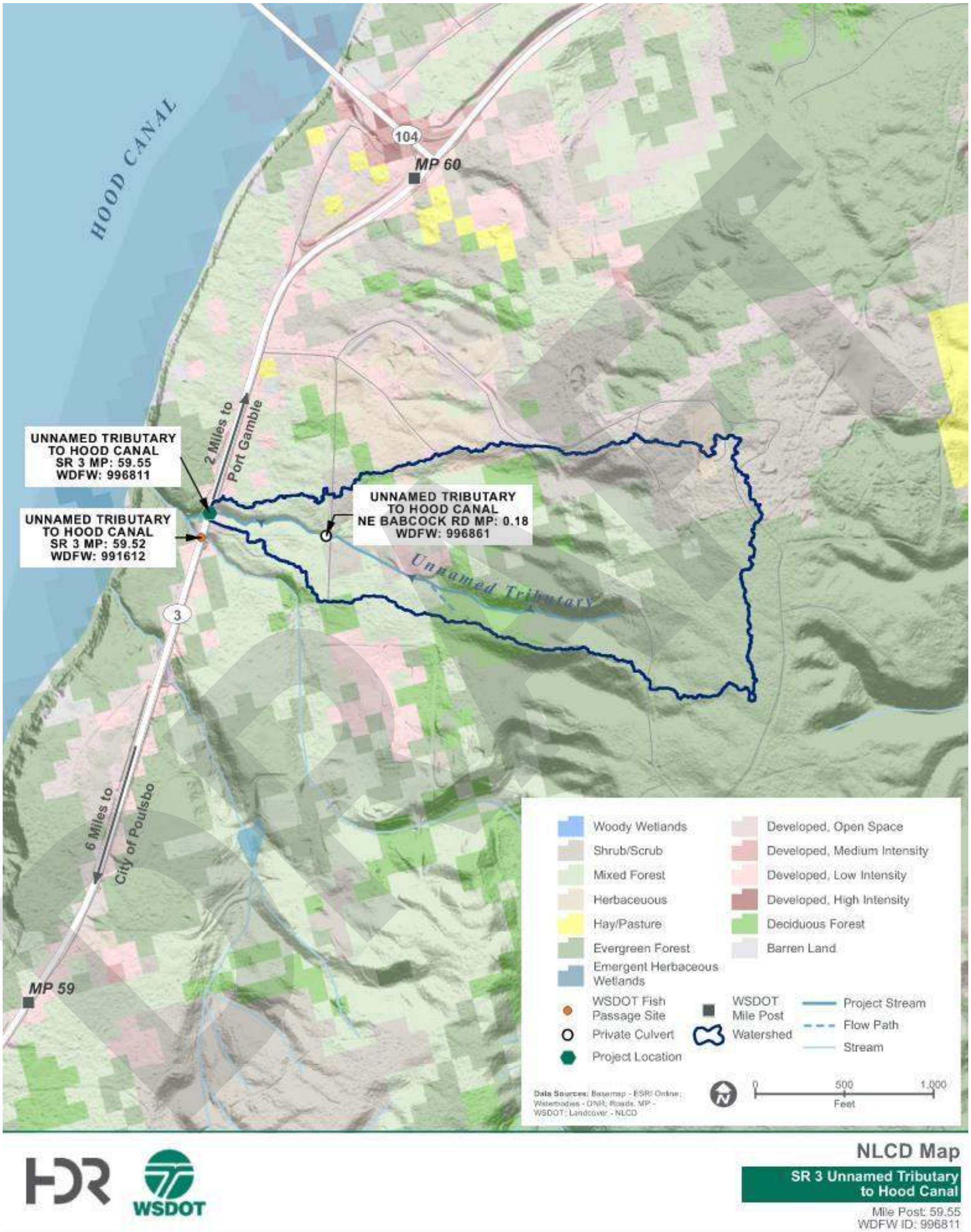

Figure 3: Land cover map (NLCD 2016)

2.3 Geology and Soils

Geologic information for the basin was mapped at a 1:100,000 scale (DNR 2016) and obtained from the DNR Geologic Information Portal. The geology of the watershed for this project site is composed of the geologic units described below and referenced in Figure 4. Landslide risk has not been analyzed by DNR at the crossing or basin.

- **Qgt (Pleistocene continental glacial till):** Pleistocene Age, Fraser-age
    - Mostly Vashon Stade in western Washington
    - Clay, silt, sand, and gravel; gray to brown and yellowish brown where oxidized; unstratified and highly compact; angular to subrounded; low permeability and porosity; includes moraines, drumlins, striations, and flutes
- **Qga (Pleistocene continental glacial drift)**: Pleistocene Age, advance continental glacial outwash, Fraser-age
    - Sand and pebble to cobble gravel; light gray to light brown; poorly to well sorted; very compact

Glacial till (Qgt) makes up a large portion of the upper watershed. Lower in the basin and in the project area, glacial drift (Qga) is present along the stream and in the project vicinity. These types of geologic materials represent the available sediment supply to the project crossing. These glacial deposits provide an abundant source of sediment to the crossing and show that mobile sediment may be replenished from upstream supply.

The soil map units within the watershed mapped from the Natural Resources Conservation Service (NRCS) are characterized by the following descriptions (NRCS 2021) and shown in Figure 5:

- **Dystric Xerorthents**: very gravelly sandy loam, sandy and gravelly outwash and/or ablation till, stream and valley landforms
- **Indianola:** very deep, somewhat excessively drained soils formed in sandy glacial drift; on hills, terraces, terrace escarpments, eskers, and fames of drift or outwash plains at elevations near sea level
    - **Loamy sand (0–5 percent slopes):** sandy glacial outwash, somewhat excessively drained
    - **Indianola-Kitsap Complex (45–70 percent slopes):** glacial outwash, lacustrine deposits with volcanic ash in the upper part, moderately well drained
- **Poulsbo**: moderately to well drained, moderately deep to cemented pan soils that form in sandy glacial till on uplands
    - **Gravelly sandy loam (0–6 percent slopes):** wet soils, basal till with volcanic ash in the upper part, moderately well drained
    - **Gravelly sandy loam (6–15 percent slopes):** wet soils, basal till with volcanic ash in the upper part, moderately well drained

    - **Gravelly sandy loam (15–30 percent slopes):** basal till with volcanic ash in the upper part, moderately well drained
    - **Poulsbo-Ragnar complex (6–15 percent slopes):** glacial outwash with some volcanic ash in the upper part, well drained, wet soils

- **Ragnar**: glacial outwash with some volcanic ash in the upper part, fine sandy loam, very low available water capacity, droughty soils

    - **Fine sandy loam (0–6 percent slopes):** glacial outwash with some volcanic ash in the upper part, well drained
    - **Ragnar-Poulsbo complex (15–30 percent slopes):** basal till with volcanic ash in the upper part, moderately well drained

The soil map indicates that Dystric Xerorthents, Indianola, and Poulsbo are present in the riparian corridor upstream of the crossing and represent the upstream sediment supply. Poulsbo soils represent the majority of the watershed, indicating that the upstream sediment supply mainly consists of moderately well drained, wet soils. Further coordination is needed with the HQ Geotechnical Scoping lead to see if additional geotechnical data are necessary.

Figure 4: Geologic map

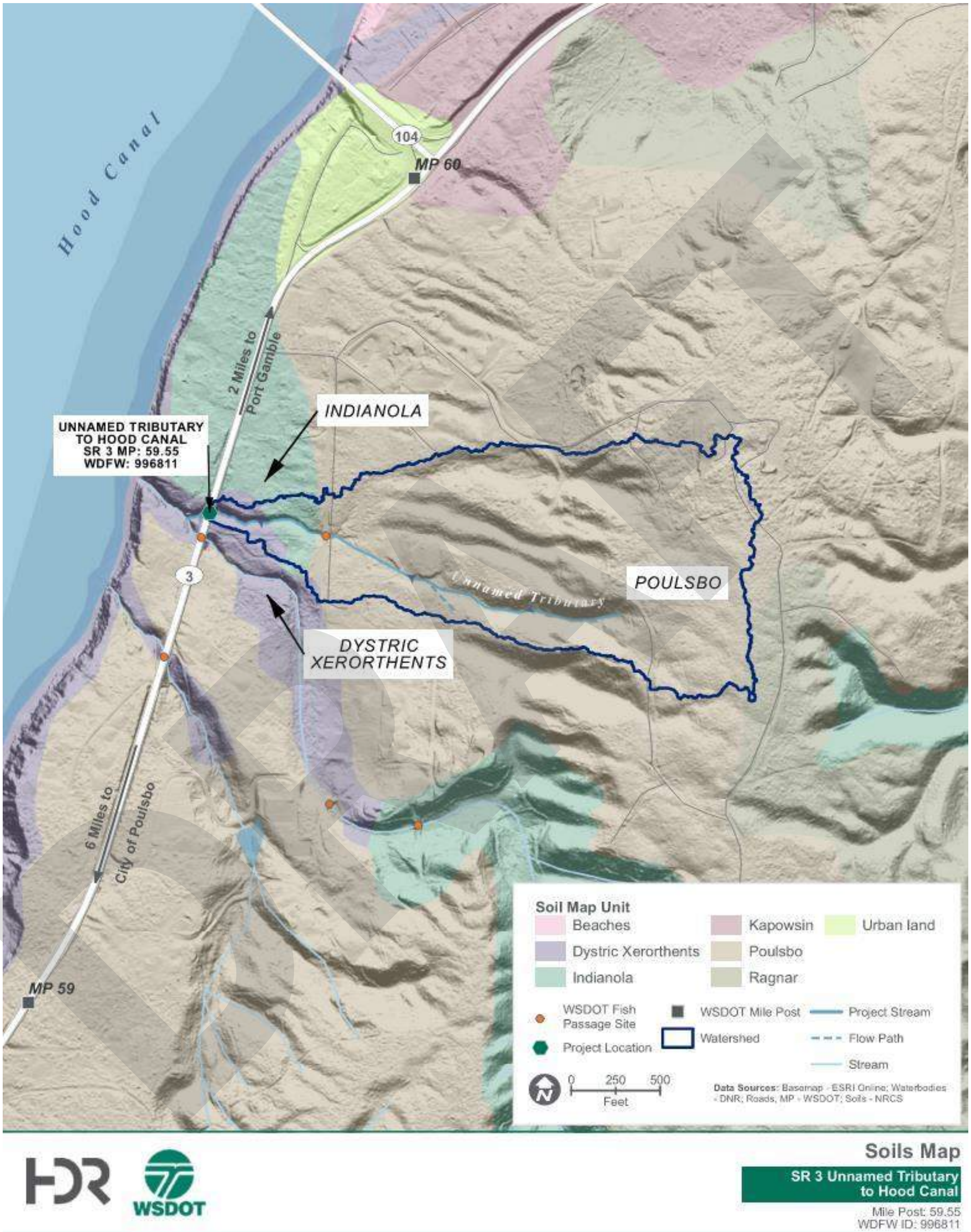

Figure 5: Soils map

2.4 Fish Presence in the Project Area

UNT to Hood Canal (through WDFW ID 996811) joins with UNT to Hood Canal (from crossing WDFW ID 991612). The channel flows out to the Hood Canal approximately 400 feet downstream of the confluence. No fish were observed in the project reaches during the field visit. UNT to Hood Canal that travels through WDFW ID 996811 is not mapped in the Statewide Washington Integrated Fish Distribution (SWIFD) data set and WDFW SalmonScape (WDFW 2022a), and StreamNet online data (2022). SWIFD is managed by WDFW and the Northwest Indian Fisheries Commission (NWIFC). A constructed dam with a 27-inch (in) water surface drop was identified (WDFW site ID 600386) during the site visit as a partial barrier approximately 130 feet downstream of the culvert outlet. This constructed dam was also referenced in WDFW SalmonScape (WDFW 2022a) and the WDFW database identifies this dam as a barrier (WDFW 2019). Because the project site is not in the SWIFD or SalmonScape and fish presence is extrapolated from nearby mapped tributaries for which fish presence data are documented. Therefore, UNT to Hood Canal (WDFW ID 996811) is presumed to potentially contain coho salmon (*Oncorhynchus kisutch*), chum salmon (*Oncorhynchus keta*), steelhead trout (*Oncorhynchus mykiss*), as well as coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) (SWIFD 2018; WDFW 2022a, 2022b; StreamNet 2022). The project reach does not provide suitable spawning habitat used by the larger salmon species such as Chinook salmon (*Oncorhynchus tshawytscha*). Chinook salmon are documented to occur in Hood Canal and some of its larger rivers to the southwest but do not occur in any streams along the eastern shoreline near UNT to Hood Canal. Out-migrating juveniles move out through Hood Canal to the ocean and would not disperse up UNT to Hood Canal or the project reach.

Coho salmon use small streams, are widespread in small rivers throughout western Washington, and can be found in many small coastal streams with year-round flow. Coho salmon presence is documented in nearby streams to UNT to Hood Canal and are therefore presumed to be potentially present in UNT to Hood Canal, which is not mapped in online databases (SWIFD 2018; WDFW 2022a, 2022b; StreamNet 2022). Once barriers are removed, coho salmon could make use of spawning and rearing habitat in UNT to Hood Canal upstream of the project culvert. Juveniles overwinter for at least 1 year throughout rivers and tributaries prior to migrating out to the ocean and rearing habitat is present throughout the surveyed reaches.

Chum salmon also are widespread in coastal streams with low gradients and velocities and the lower reaches of larger rivers, and often use the same streams as coho, but chum generally spawn closer to salt water. Chum salmon fry do not rear in fresh water for more than a few days and quickly move downstream to the estuary and rear there for several months before heading out to the open ocean. Chum salmon are documented in nearby streams to UNT to Hood Canal but are unlikely to be present in the project crossing at UNT to Hood Canal because of the high gradient (SWIFD 2018; WDFW 2022a, 2022b; StreamNet 2022). The channel has a slope of 6.8 percent.

Steelhead trout are present throughout many western Washington streams and rivers and are documented in several streams and rivers that flow into Hood Canal (SWIFD 2018; WDFW 2022a, 2022b; StreamNet 2022). They generally prefer fast water in small to large mainstem rivers and medium to large tributaries. Steelhead life history is highly variable, and juveniles typically spend 1 to 3 years rearing in fresh water (Wydoski and Whitney 2003). Juveniles disperse into tributaries and off-channel habitat during high winter flows and could potentially use the UNT to Hood Canal for this purpose and make use of rearing habitat in the project reach. Steelhead in Hood Canal and its tributaries are part of the Puget Sound Steelhead Distinct Population Segment and are also listed as threatened under the Endangered Species Act (ESA) (NMFS 2007).

Coastal cutthroat trout are also documented to occur in many streams and rivers that flow into Hood Canal (SWIFD 2018; WDFW 2022b). They seek smaller streams with minimal flow and small gravel substrate including sand. They prefer the uppermost portions of these streams, areas that are generally too shallow for other salmonids. They can be anadromous and rear in streams for 2 to 3 years or be resident and remain entirely in fresh water (Wydoski and Whitney 2003). Because of the fish passage restrictions, cutthroat trout that potentially inhabit the UNT to Hood Canal upstream are resident, but with barrier removal a sea-run population could be supported.

Table 2 lists native fish species potentially present within the project area.

Table 2: Native fish species potentially present within the project area

Species	Presence (presumed, modeled, or documented)	Data source	ESA listing
Coho salmon (*Oncorhynchus kisutch*)	Presumed based on presence documented in Hood Canal	SWIFD 2018, StreamNet 2022, WDFW 2022a, WDFW 2022b	Not warranted
Puget Sound steelhead (*Oncorhynchus mykiss*)	Presumed based on presence documented in Hood Canal	SWIFD 2018, StreamNet 2022, WDFW 2022a, WDFW 2022b	Threatened
Coastal cutthroat trout (*Oncorhynchus clarkii clarkii*)	Presumed based on presence documented in Hood Canal	SWIFD 2018, WDFW 2022b	Not warranted

2.5 Wildlife Connectivity

The 1-mile-long segment that UNT to Hood Canal falls in is not a ranked priority for Ecological Stewardship and does not have a ranked priority for Wildlife-related Safety by WSDOT HQ ESO. Adjacent segments to the north and south ranked low. The rankings were obtained from the WSDOT Habitat Connectivity Investment Priorities database (WSDOT 2018). At the time this Preliminary Hydraulic Design (PHD) Report was written, the wildlife connectivity analysis was pending for this crossing and will be provided by WSDOT. Additional width or height has not been recommended by WSDOT HQ ESO for wildlife connectivity purposes.

2.6 Site Assessment

The following sections describe the existing conditions of UNT to Hood Canal observed during the site visits.

2.6.1 Data Collection

HDR Engineering, Inc. (HDR) conducted an independent site visit on March 15, 2022, to measure BFWs, collect pebble count data, and identify reference reaches. HDR also documented stream conditions and assessed fish habitat character and quality within the project reach during the site investigation. HDR walked the stream approximately 300 feet upstream and approximately 60 feet downstream of the existing culvert crossing. A second site visit with HDR, WSDOT, WDFW, and the Suquamish tribe was conducted on April 27, 2022, to gain concurrence on reference reach location, sediment size complexity of the site, and BFW measurements. Full details of these site visits are presented in the Hydraulic Field Report included in Appendix B.

HDR collected 11 BFW measurements and one pebble count upstream of the culvert crossing, and one pebble count downstream of the crossing throughout both the reconnaissance site visit and the concurrence visit. Figure 6 shows the locations of these BFW measurements and the details of the BFW measurements are summarized in Section 2.7.2. The streambed material consisted primarily of sand, gravel, and cobbles. Pebble counts are summarized in Section 2.7.3.

A reference reach approximately 40 feet long was identified approximately 120 to 160 feet upstream of the culvert inlet, as shown in Figure 6. Cross-section geometry in the reference reach was used to inform the channel design. A pebble count, BFW measurement, and valley width measurement were taken in the reference reach.

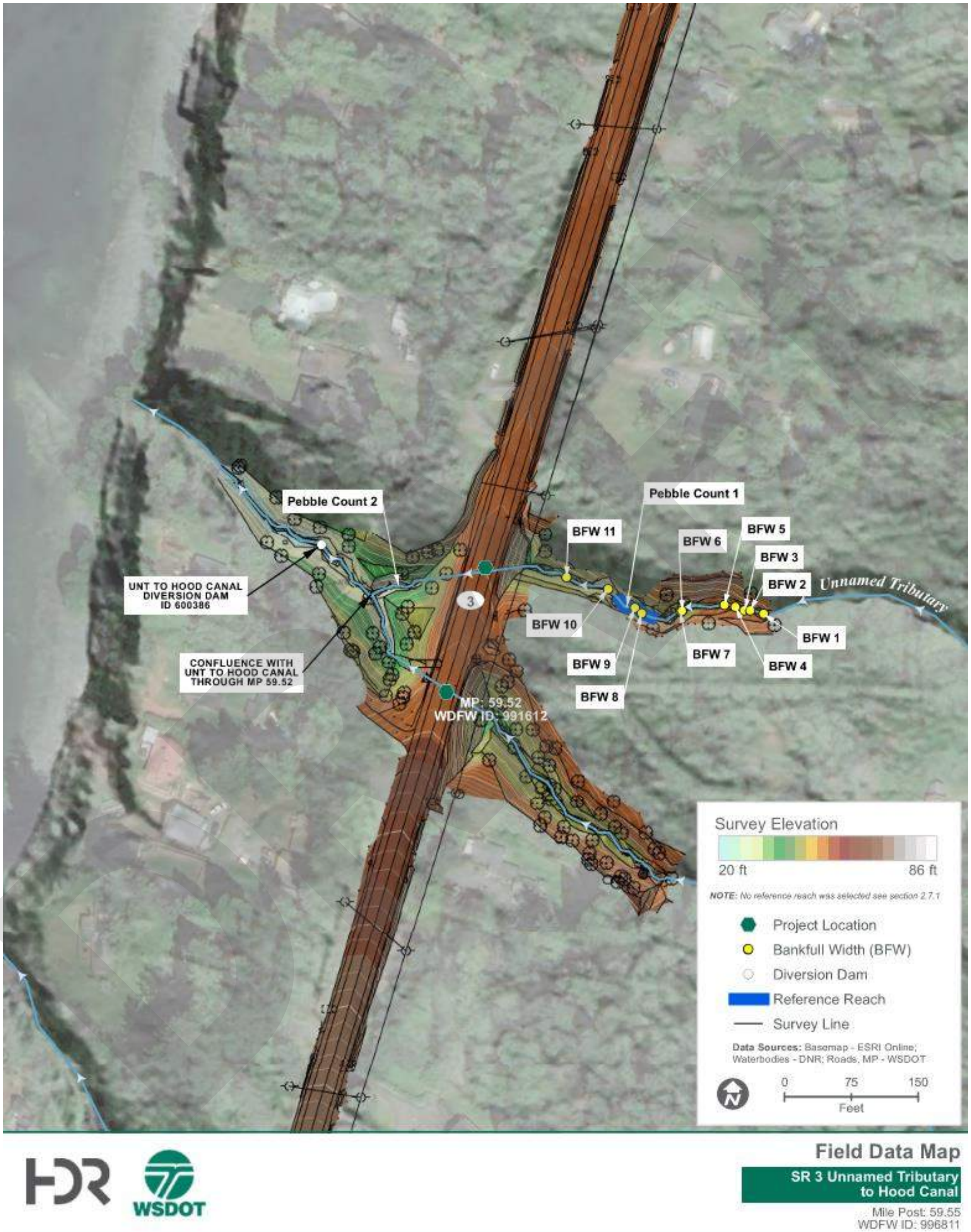

Figure 6: Reference reach, bankfull width, and pebble count locations

2.6.2 Existing Conditions

The following paragraphs and figures describe field observations of UNT to Hood Canal from upstream to downstream. The existing culvert crossing is a 120-foot-long, 2-foot-diameter RCP culvert at a 7.8 percent slope. At the inlet, the road has a fill depth of approximately 23 feet and the existing culvert alignment is skewed approximately 8 degrees from a perpendicular angle to SR 3. The slope of the existing culvert creates a fish passage barrier for salmonids moving upstream. The small, steep stream is potentially used by coho salmon as well as steelhead and cutthroat trout. Spawning habitat is lacking so the stream functions as a migratory corridor for juvenile fish of these species to move up into rearing habitat, particularly for overwintering before moving out into Hood Canal. The undersized culvert prevents natural stream processes including woody material and sediment transport. Figure 7 shows a field sketch of a plan view and cross sections of the UNT to Hood Canal upstream and downstream of the crossing with stationing that applies only to Section 2.6.2. The stationing in the upstream reach starts at station (STA) 0 at the culvert inlet and increases from downstream to upstream. Downstream, the stationing starts at STA 0 at the culvert outlet and increases from upstream to downstream. As-builts for the crossing provided by WSDOT show the rough location and cross-sectional shape of the historical channel. The channel is not drawn in detail on the as-builts so it was not used as a reference. No obvious signs of maintenance activity were observed.

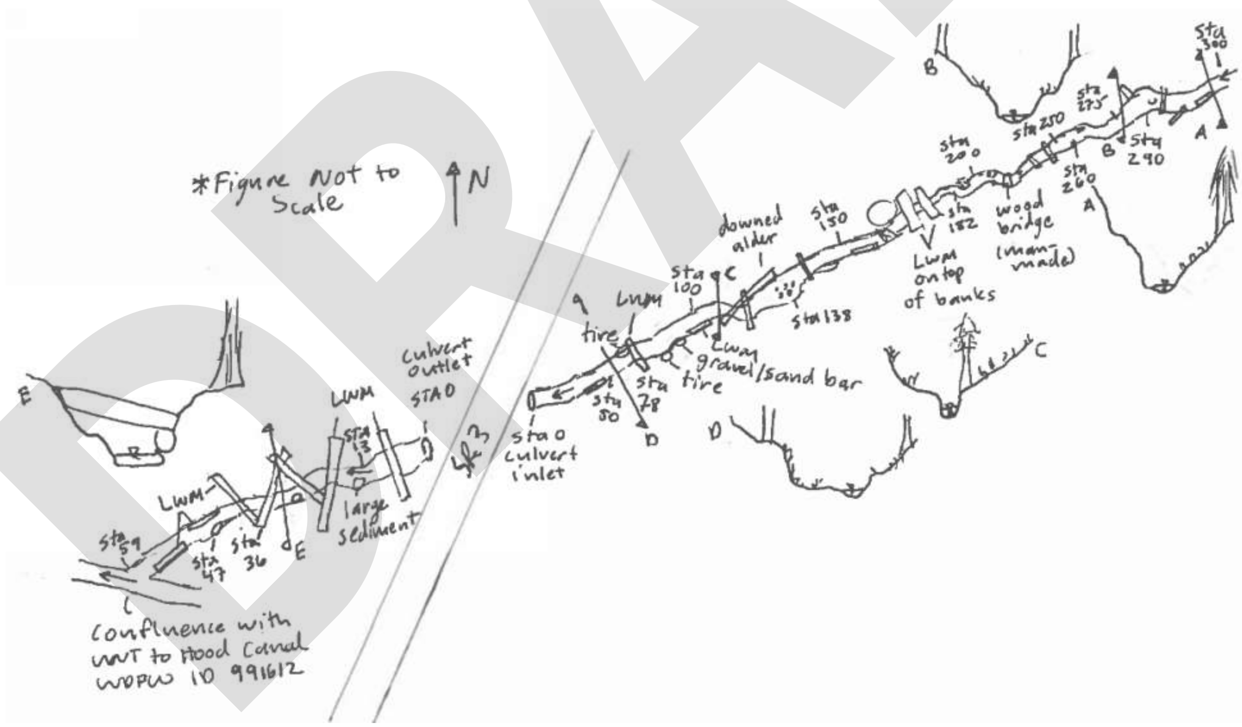

Figure 7: Plan view and cross sections of UNT to Hood Canal

2.6.2.1 Upstream

From the culvert inlet to 300 feet upstream of the inlet, the channel is relatively consistent. In this reach the stream is a well-defined, single-threaded channel with abundant small and large woody material (LWM). The overall planform is straight, but within the straight path the reach has tight bends and meanders largely influenced by woody material. The small woody material is less than 1 foot in diameter and forms natural steps. The channel’s step-pool morphology is forced by LWM and, to a lesser extent, large cobbles. The cross-sectional channel shape is frequently non-uniform and characterized by a meandering thalweg directed by woody material or sediment deposits. Where there is no woody material, the channel shape is uniform and U-shaped within defined banks. The bed throughout the upstream reach consists of small gravels and sand, with some small cobbles observed. The channel is confined within banks that vary from steeply sloping to vertical, and 1 to 3 feet high. The top of bank to the valley toe is generally steep and sparsely vegetated by ferns and small trees. Large mature trees were abundant between the valley toe and top of bank. Variability within these general characteristics in the upstream reach is described in the subsequent paragraphs moving from upstream to downstream.

The field reconnaissance survey began approximately 300 feet upstream of the culvert inlet. Here, the channel shows signs of incision with approximately a 3-foot vertical left bank and is undercut with LWM positioned parallel to the flow along the left bank. Smaller woody debris (Figure 8) is scattered throughout a small section between STA 2+90 and STA 3+00 that act as steps. At STA 2+90 the channel bed consists of a range of particles from sand to cobbles (Figure 9). The cobbles and small woody debris force the thalweg to meander.

Figure 8: Small woody material at STA 3+00 (looking across channel at the left bank)

Figure 9: Streambed material and shape looking downstream of STA 2+90 (looking downstream)

The channel and bank interactions start to vary as the channel meanders back and forth and the accessible floodplain varies from right to left. The left bank has an accessible floodplain at STA 2+75 and the right bank has an accessible floodplain at STA 2+60. The channel bed composition changes slightly farther downstream as the cobbles decrease and sand and fines abundance increase at STA 2+50 (Figure 10). Small woody debris abundance also increases in this area, creating step-like features (Figure 11), and shifts the thalweg from the right to left bank. Banks are approximately 1 foot high at this location. At approximately STA 2+25 a small, constructed, moss-covered plank (Figure 12) spans across the banks. The state of the plank indicates that the flow does not usually reach the height of the plank, wood of this size and location would not readily be transported, and banks are stable here.

Figure 10: STA 2+50 channel and bed composition (looking downstream)

Figure 11: Looking upstream, small woody debris forming step-like feature (looking upstream)

Figure 12: Plank across channel (upstream to the right of the photograph—looking at right bank)

At STA 2+00 the floodplains narrow and the banks are more vertical with drops of 1 to 2 feet. Immediately upstream of STA 1+82, small cobbles and large gravels have deposited on the inside of a bend on the right bank. From approximately STA 1+82 to STA 1+62 the river flows under a natural bridge made by two LWM pieces spanning across the banks (Figure 13). Soil and debris have accumulated on top of the LWM pieces, forming a partially enclosed natural bridge, forcing flow underneath the natural bridge and influencing channel shape. BFW measurements were taken outside of the influence of this feature. At the exit of the natural bridge, the water surface drops approximately 1 foot over small woody material.

Figure 13: Flow going under natural bridge at STA 1+82 (looking downstream)

Downstream of the drop, the thalweg is shifted to the left bank by a large alder and its roots occupying the right bank. The flow continues along the left side of the channel, flowing over a piece of wood that has been embedded within the channel. It makes up the channel bed for approximately 10 feet (Figure 14). At STA 1+50 the left bank is nearly vertical. From approximately STA 1+82 to STA 1+40 the bed consists mostly of sands and fines except for a small deposit of gravel and sand on the left bank at STA 1+45. At STA 1+40 the channel widens and small cobbles become abundant and the banks are not as vertical (Figure 15).

Figure 14: LWM as channel bed on left bank (top of the page is downstream, picture facing left bank)

Figure 15: Cobbles and stream condition in reference reach (looking downstream)

A D_{100} value of 10 inches was measured at STA 1+38. At STA 1+30 the channel narrows again and a downed alder lines the right bank and crosses the channel at STA 1+15 as the channel meanders to the right, and the banks narrow (Figure 16). Downstream of STA 1+00 the bed consists of cobbles, gravels, sand, and fines and LWM parallels the left bank. At STA 0+90 a deposit of gravel and sand forms on the left bank and the channel continues with no access to the floodplain with approximately 2-foot-high vertical and narrow banks. At STA 0+78 a 1.5-foot-diameter downed tree spans across the banks of the channel (Figure 17) and approximately 15 feet farther downstream another downed tree with a diameter of 1 foot spans the banks. Two tires were observed in this section of the stream on the left and right banks, indicating an anthropomorphic influence in the stream. At STA 0+50 the channel floodplains become wider and become more accessible on the right bank. Approaching the culvert inlet (Figure 18), the stream cascades down at a steep slope through woody material and cobbles from STA 0+06 to STA 0+00 before entering the culvert. The culvert is mostly free of debris and sediment obstructing flow, but has a negligible amount of fines and sticks deposited immediately at the culvert inlet. A small inflow from road drainage was observed on the right bank at STA 0+00.

Figure 16: LWM lining right bank and channel banks narrowing (looking downstream)

Figure 17: LWM spanning across banks (looking downstream)

Figure 18: Culvert inlet at SR 3 WDFW site ID 996811 (looking downstream)

Figure 19: General channel characteristics downstream (looking upstream)

2.6.2.2 Downstream

The downstream reach is similar to the upstream reach but has larger step-pool features and has higher banks than the upstream reach (Figure 19). Larger LWM was observed in the downstream reach, approximately 2 to 3 feet in diameter, spanning the channel banks.

The culvert is unobstructed and outlets into a scour pool (Figure 20) with the right and left banks undercut in the vicinity of the outlet (Figure 21). Immediately downstream of the outlet LWM spans the channel and the bed consists of sand and gravel (Figure 22). Downstream of the LWM that spans over the top of bank, the flow follows the right bank at STA 0+13, directed away from the left bank by small woody material and large cobble.

Figure 20: Culvert outlet at SR 3 WDFW site ID 996811 (looking upstream)

Figure 21: Undercut bank at scour outlet (looking upstream at right bank)

Figure 22: LWM spanning across bank downstream of culvert outlet (looking downstream)

Downstream of STA 0+13, the flow travels under four more channel-spanning LWM pieces through STA 0+36 (Figure 23). The banks at this location are approximately 1 to 2 feet high. Through this reach, the channel consists of mostly gravels and sand with some cobbles. The channel continues to cascade through the cobbles and woody material for another 20 feet before dropping approximately 16 inches on the left side of the channel as flow is directed away from the right bank by cobbles and small woody material (Figure 24). After the drop the channel travels through a flatter reach and the bed consists of gravel and sand. Hardpan is present on the left bank at STA 0+45 (Figure 25). LWM parallels the left bank immediately before the downstream reach ends at STA 0+59 at the confluence with UNT to Hood Canal depicted in Figure 26. Figure 27 shows where UNT to Hood Canal meets the Hood Canal downstream of the reconnaissance survey extents.

Information pertaining to site descriptions downstream of the confluence can be found in the PHD Report for UNT to Hood Canal, WDFW site ID 991612.

The impact of existing conditions on fish in the project site are described in section 2.6.3.

Figure 23: LWM spanning across channel (looking upstream)

Figure 24: 16-inch drop from the right to the left side of the channel (looking upstream)

Figure 25: Hardpan on left bank (looking upstream)

Figure 26: Looking upstream toward confluence with UNT to Hood Canal (WDFW site ID 996811) on page left with the UNT to Hood Canal (WDFW site ID 991612) on page right

Figure 27: UNT to Hood Canal meeting the Hood Canal

2.6.3 Fish Habitat Character and Quality

Upstream of the SR 3 crossing, UNT to Hood Canal flows through a wide, forested corridor between a few residential properties. The forest surrounding the upstream reach is a mature mixed forest with a dense shrub understory dominated by native woody shrub species and ferns along both banks. Patches of non-native Himalayan blackberry (*Rubus armeniacus*) and English ivy (*Hedera helix*) are present near the downstream end of the surveyed reach near SR 3. The mature forest and shrub cover provide good shading, nutrient inputs, and potential for LWM recruitment. LWM is important in western Washington streams in that it provides cover for fish and contributes to stream complexity, which is beneficial to salmonids. Several downed logs and woody material were present within the stream channel and banks throughout the surveyed reach. Several debris jams and small branches were located in the stream channel throughout the upstream reach and two large stumps with their root systems in the banks. The presence of LWM provides habitat complexity and cover for salmonids for rearing and migration.

Pools, and the transition areas between pools and riffles, are important habitat for adult and juvenile salmon. The slow water of pools allows the fish to rest, and the depth provides protection from predators, as well as cooler water. The stream is small and shallow, and instream habitat consists predominantly of shallow riffles and pool habitat was generally lacking. There were only two small pools associated with LWM and bank scour. The lack of pool habitat reduces the function of this reach for juvenile salmon rearing.

The channel bed throughout the upstream reach consists predominantly of gravel and fines, with some small cobbles in a few higher-gradient areas. The upstream reach generally lacks suitable spawning habitat for coho salmon and cutthroat trout, which make use of small to medium-sized gravels. The substrate is generally embedded with fines and lacks areas of suitable spawning gravels, although a few small areas may support spawning of cutthroat trout. The reach does provide migratory and some rearing habitat for these species as well as for juvenile steelhead that potentially may overwinter in the stream.

The downstream reach of UNT to Hood Canal flows through a forested ravine with an open understory along both banks dominated by ferns and some native shrubs including salmonberry (*Rubus spectabilis*) and osoberry (*Oemleria cerasiformis*). Non-native English ivy is also prevalent in the upper end of this reach near the road embankment and residential driveway. The mature mixed forest in this reach provides good shading for the stream as well as potential for LWM recruitment. The shrubs along the banks in the lower part of the reach provide some cover along the banks as well as nutrient inputs. LWM was present throughout the downstream reach and most consisted of large conifer logs. There were 5 pieces of LWM in and across the channel within the surveyed reach between the culvert outlet and the confluence with UNT to Hood Canal flowing though WDFW site ID 991612, and a large cedar stump forming the left bank at the confluence.

The instream habitat throughout the downstream reach consists of a channel with high banks with flow that cascades down over a series of step pools. Three step pools throughout the downstream reach ranged in size from approximately 3 to 4 feet wide and were only up to approximately 3 to 4 inches deep at the time of the field visit. Below these step pools the stream joins with a UNT to Hood Canal flowing though WDFW site ID 991612.

Substrate in the downstream reach is dominated by gravels and fines, with some riffle areas with cobble. Habitat throughout the downstream reach is primarily suited to rearing and migration as spawning gravel areas with small to medium-sized gravel suitable for species such as coho salmon and cutthroat trout are limited. The presence of LWM, and riffle and step-pool morphology, provide instream habitat complexity suitable for rearing salmonids, although the pools are small and limited in function for cover and resting areas. Instream habitat in the downstream reach is suited to migration and some rearing for juvenile coho salmon and steelhead, as well as cutthroat trout. The lack of pool habitat limits the function of this reach for rearing.

Information pertaining to site descriptions downstream of the confluence can be found in the PHD Report for UNT to Hood Canal, WDFW site ID 991612.

2.6.4 Riparian Conditions, Large Wood, and Other Habitat Features

The riparian corridor affects the aquatic system through influences on stream hydrology, sediment dynamics, biochemistry and nutrient cycling, temperature, physical habitat, and food web maintenance. The forested areas upstream of the crossing are bounded by several residential properties, but farther upstream of the surveyed reach the stream is located within a large, forested timber management area. The riparian corridor in the upstream reach of the UNT contains mature mixed forest that provides potential LWM recruitment. The riparian corridor is a mature mixed forest consisting of red alder (*Alnus rubra*), bigleaf maple (*Acer macrophyllum*), western hemlock (*Tsuga heterophylla*), Douglas fir (*Pseudotsuga menziesii*), and some western red cedars (*Thuja plicata*). A dense shrub understory is located along both banks. The understory in areas near the culvert inlet and roadway contains patches of non-native

Himalayan blackberry as well as English ivy, particularly along the right bank. Farther upstream the shrub understory is dominated by more native species including salmonberry, vine maple (*Acer circinatum*), willow (*Salix sp*.), osoberry, and several species of ferns.

Large logs and LWM in general were sparse throughout the upstream reach. Six pieces of LWM in and across the channel within the surveyed upstream reach ranged from approximately 8 to 16 inches in diameter. Several debris jams and many smaller branches and several rootwads were located in the banks throughout the upstream reach. The stream is small and shallow, and consisted predominantly of shallow riffles over gravel, and some cobble. Pools were lacking throughout the upstream reach with only a few small shallow pools associated with LWM and scour.

The downstream reach flows through a forested ravine with steep side slopes consisting of mature mixed forest. The mixed forest is dominated by western red cedars and red alder, and also contained bigleaf maple and Douglas fir. The riparian corridor is bounded by residential properties to the north and south of the ravine. The understory in the upper part of the reach is open and dominated by sword ferns, and farther downstream by the confluence with the other UNT, the shrub layer becomes denser along both banks and is dominated by native woody shrub species including salmonberry, osoberry, and vine maple.

The LWM in the relatively short downstream reach is more abundant than upstream and consists mostly of downed conifers. There were five pieces of LWM in and across the channel within the surveyed downstream reach between the culvert and the confluence with the other UNT that ranged from 10 to 36 inches in diameter. The downstream reach consists predominantly of a series of riffles and shallow step pools. Based on site observations, LWM has been transported from upstream and has been recruited from windfall. The density of existing material is less than the 75th percentile of the guidelines presented in Fox and Bolton (2007).

No beaver activity was observed in the upstream or downstream reach.

Information pertaining to site descriptions downstream of the confluence is provided in the PHD Report for UNT to Hood Canal, WDFW site ID 991612.

2.7 Geomorphology

Geomorphic information provided for this site includes selection of a reference reach, the geometry and cross sections of the channel, and stability of the channel both vertically and laterally of UNT to Hood Canal.

2.7.1 Reference Reach Selection

A 40-foot-long segment of stream from approximately 120 to 160 feet upstream of the culvert was selected as the reference reach. The stream condition of the reference reach is depicted in Figure 28. The reference reach has an average gradient of 6.8 percent, based on the topographic survey. The reference reach location was chosen because it is most representative of naturally occurring conditions with the least amount of disturbance from development. Downstream of the reference reach, but upstream of the culvert the channel slope is impacted by sedimentation from the undersized culvert. Upstream of the chosen reference reach, the channel has segments with undercut banks and LWM obstructing the channel. The downstream reach was not chosen as a reference reach because it has a slope of nearly 12 percent, is incised at the culvert outlet, and has a confluence with UNT to Hood Canal (that traveled through WDFW site ID 991612) 60 feet downstream of the culvert outlet of WDFW site ID 996811. The area between the confluence and incised area at the culvert outlet is not representative of the overall channel conditions and slope.

A pebble count and two BFW measurements (BFWs 8 and 9) were collected within the reference reach. The material observed consists primarily of sand, gravel, and cobbles. BFW measurements are presented in Section 2.7.2 and streambed sediment observations are discussed in Section 2.7.3. The location of the reference reach and BFW measurement locations are shown in Figure 6 in Section 2.6 above. This reference reach was used to inform the design of the proposed channel shape.

Figure 28: Reference reach, looking downstream with BFW 8 of 6.3 feet

2.7.2 Channel Geometry

HDR conducted an independent site visit on March 15, 2022, to measure BFWs, collect pebble count data, and identify a reference reach. A second site visit with HDR, WSDOT, WDFW, and the Suquamish tribe was conducted on April 27, 2022, to gain concurrence on the reference reach location and BFW measurements. From the concurrence meeting 10 BFW measurements were collected upstream in the field. They ranged from 3.5 to 7.9 feet and were all used in the design average BFW of 6.0 feet. The 11 measurements used in the design average are shown in Figure 6; this is a combination of the measurements taken from the reconnaissance and concurrence site visits. This design average was used as a starting point for determining the minimum hydraulic opening (MHO). Photographs showing the stream condition and BFW measurement are displayed in Figure 29 through Figure 34. Figure 35 shows typical cross sections of the channel at each BFW measurement location. Only six BFW measurement locations are presented in this figure for clarity.

After reviewing the small drainage area and associated hydrology, as well as the hydraulic modeling results (Sections 3 and 5), the BFWs measured were determined to likely be conservative. One of the challenges associated with a stream of this size was to determine bankfull indicators in the field; many of the usual signs were not present, and preference was given to geometric shape and breakpoints in the terrain in order to determine BFW. This method provided larger BFW values, corresponding to a structure size with a greater factor of safety over modeled 2-year top width values.

The single-threaded sinuous channel in the reference reach has well-defined banks. The channel is generally U-shaped but is defined by a meandering thalweg that creates an asymmetrical, cross-sectional geometry as described in Section 2.6.2. In the reference reach at BFWs 8 and 9, the channel bottom width between the toes is approximately 1.5 feet and the channel width is approximately 4.0 feet, measured from the top-of-bank grade breaks. The banks are nearly vertical and slope up from the toe with a slope of 1:1. This channel shape is consistent throughout the project reach upstream. The floodplains are visible and accessible in some sections such as the reference reach and the banks are comprised of fines and small to large gravel. The channel slope in the reference reach is 6.8 percent. The total surveyed upstream channel, from 300 feet upstream of the culvert inlet, is 6.4 percent. The reference reach slope will guide the proposed design slope, and the proposed cross section will be based on the channel shape in the reference reach.

The width-to-depth ratio, measured from the reference reach cross sections, is 8.5:1. The channel evolution stage was evaluated in the reference reaches and estimated to be in Stage IV of the Channel Evolution Model (Schumm et al. 1984). The size of the stream and its associated minimal power have not displayed active signs of incision based on field observations; though site observations show incision and migration may have occurred in the past (Section 2.7.4). Table 3 shows BFW measurements collected during the site reconnaissance meeting and concurrence meeting.

Table 3: Bankfull width measurements

BFW number	Width (ft)	Included in design average?	Location measured (distance from culvert inlet in feet)	Station (ft)	Concurrence notes
1	5.3	Yes	295	57+15	Stakeholder concurred on 4/27/2022
2	6.0	Yes	280	57+00	Stakeholder concurred on 4/27/2022
3	5.4	Yes	274	56+94	Stakeholder concurred on 4/27/2022
4	6.5	Yes	263	56+83	Stakeholder concurred on 4/27/2022
5	3.5	Yes	250	56+70	Stakeholder concurred on 4/27/2022
6	4.5	Yes	200	56+20	Stakeholder concurred on 4/27/2022
7	6.3	Yes	198	56+18	Stakeholder concurred on 4/27/2022

BFW number	Width (ft)	Included in design average?	Location measured (distance from culvert inlet in feet)	Station (ft)	Concurrence notes
8 (reference reach)	6.3	Yes	150	55+70	Stakeholder concurred on 4/27/2022
9 (reference reach)	7.9	Yes	139	55+59	Stakeholder concurred on 4/27/2022
10	7.1	Yes	100	55+20	Stakeholder concurred on 4/27/2022
11	6.7	Yes	50	54+70	Stakeholder concurred on 4/27/2022
Design average	**6.0**				

Figure 29: BFW 1 measurement and stream condition (looking upstream)

Figure 30: BFW 5 measurement and stream location (looking downstream)

Figure 31: BFW 6 measurement and stream condition (looking downstream)

Figure 32: BFW 8 measurement and stream condition (looking downstream)

Figure 33: BFW 10 measurement and stream condition (looking downstream)

Figure 34: BFW 11 measurement and stream condition (looking downstream)

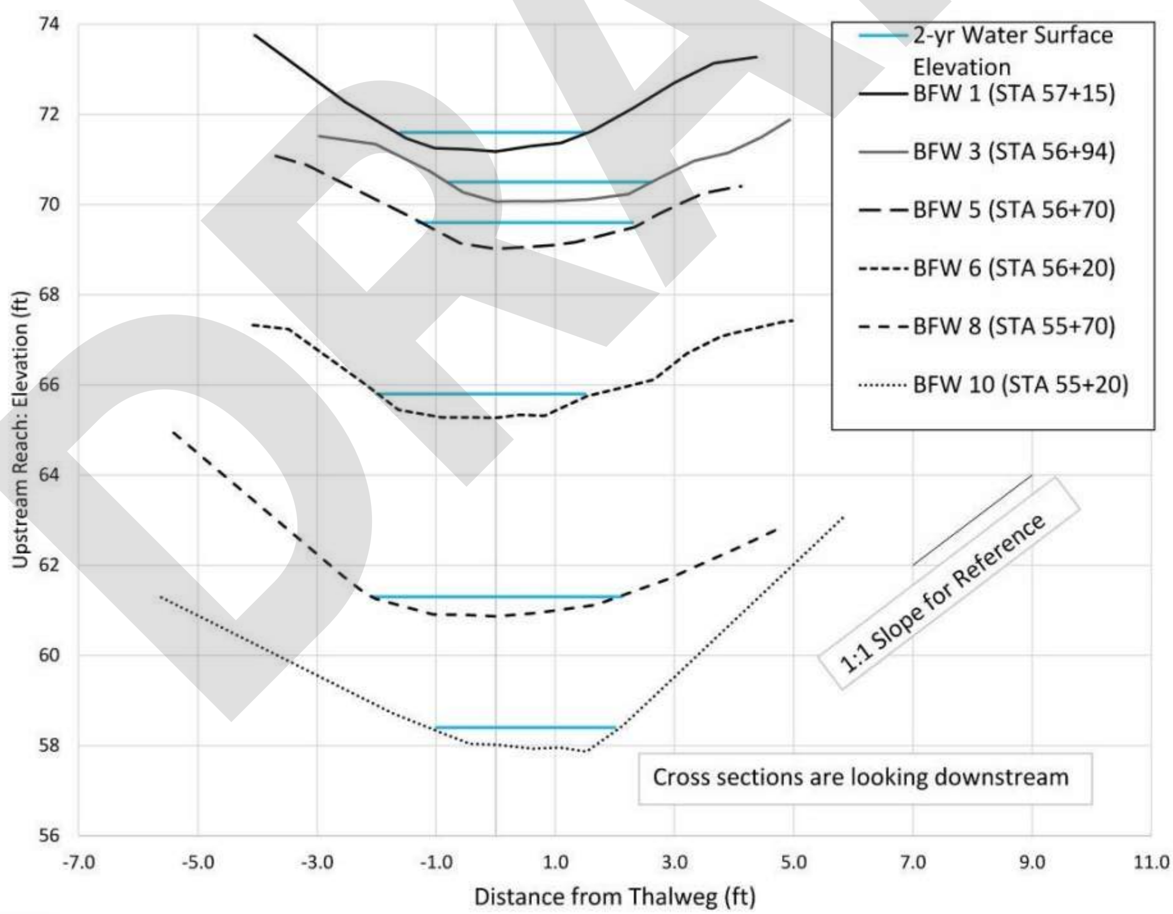

Figure 35: Existing cross-section examples

2.7.2.1 Floodplain Utilization Ratio

The floodplain utilization ratio (FUR) is determined by dividing the flood-prone width (FPW) by the BFW. A ratio under 3.0 is considered a confined channel, and a ratio above 3.0 is considered an unconfined channel. The FPW was determined from the modeled 100-year event width for existing conditions. The cross sections chosen to analyze the FUR are outside of the influence of the confluence, culvert outlet, and culvert inlet. Ten upstream cross sections, spaced approximately 25 feet apart from each other outside of these influences, were chosen to measure the FPW as depicted in Figure 36. These values were each divided by the 2-year top width based on modeling results. The BFW was not used because the BFW of 6.0 feet, when compared to modeling results, is slightly conservative and would not provide an accurate determination of the FUR. Table 4 shows each FPW, the calculated FUR, and the average FUR across all cross sections. The average result is a FUR of 1.3; therefore, the channel is confined.

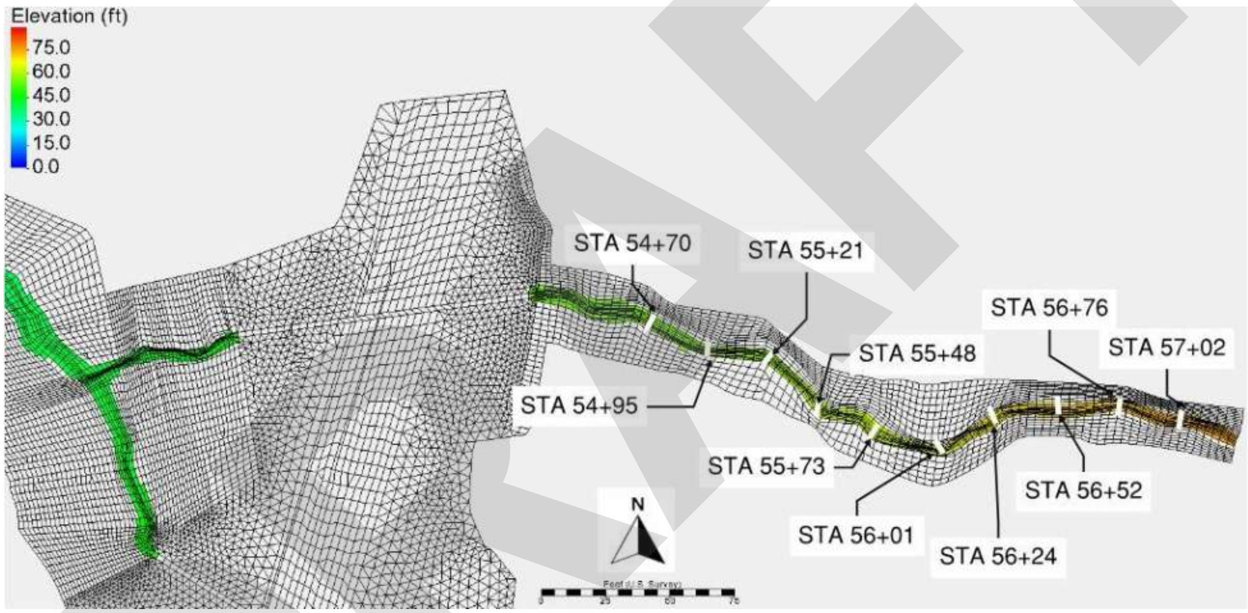

Figure 36: FUR locations

Table 4: FUR determination

Station	2-year width (ft)	FPW (ft)	FUR	Confined/ unconfined	Included in average FUR determination
54+70	4.4	5.2	1.2	Confined	Yes
54+95	3.1	4.3	1.4	Confined	Yes
55+21	3.4	4.2	1.2	Confined	Yes
55+48 (In reference reach)	3.2	4.5	1.4	Confined	Yes
55+73 (In reference reach)	5.0	6.3	1.3	Confined	Yes
56+01	2.9	3.5	1.2	Confined	Yes
56+24	3.2	4.6	1.4	Confined	Yes
56+52	4.3	5.2	1.2	Confined	Yes
56+76	3.6	4.5	1.3	Confined	Yes
57+02	4.2	5.2	1.2	Confined	Yes
Average	**3.7**	**4.8**	**1.3**	Confined	

2.7.3 Sediment

Wolman pebble counts were conducted at two locations: one upstream of SR 3, with approximately 200 particles, and one downstream of SR 3 with approximately 100 particles. The locations of these pebble counts were agreed upon during the BFW concurrence meeting. A Wolman pebble count requires approximately 100 particles to be sampled to accurately quantify sediment distributions. Two pebble counts with a total of 300 particles were sampled instead of three pebble counts with 100 particles each; substrate was consistent throughout the upstream reach and it was deemed acceptable to use one larger pebble count rather than to perform two separate pebble counts. The upstream pebble count was completed in the reference reach, shown in Figure 6 above. A combination of the two pebble counts captures the range of conditions observed throughout the upstream and downstream reaches. The cumulative distribution and specific pebble sediment sizes are provided in Figure 37 and Table 5, respectively. The average diameter for design was determined by taking the average of each D_{16} through D_{100} value for Pebble Count 1 and 2. Material consisted primarily of sand, gravel, and small cobbles as shown in Figure 38. The largest natural particle found throughout the stream of 10 inches was observed outside of the two pebble counts. Small boulders over 1 foot in diameter were observed downstream from the road embankment or were placed which appear to be immobile (see Figure 39).

Table 5: Sediment properties near the project crossing

Particle size	Pebble Count 1 (reference reach) diameter (in) (25 ft downstream of culvert outlet)	Pebble Count 2 diameter (in) (135 ft upstream of culvert inlet)	Average diameter for design (in)	Particle Type	Average diameter for design (ft)
Included in average?	Yes	Yes			
$\mathbf{D_{16}}$	0.1	0.2	0.2	Very fine gravel	0.01
$\mathbf{D_{50}}$	0.3	0.4	0.4	Medium gravel	0.03
$\mathbf{D_{84}}$	0.9	0.9	0.9	Coarse gravel	0.08
$\mathbf{D_{95}}$	1.8	2.0	1.9	Very coarse gravel	0.16
$\mathbf{D_{100}}$	7.1	5.0	6.1	Large Cobble	0.50

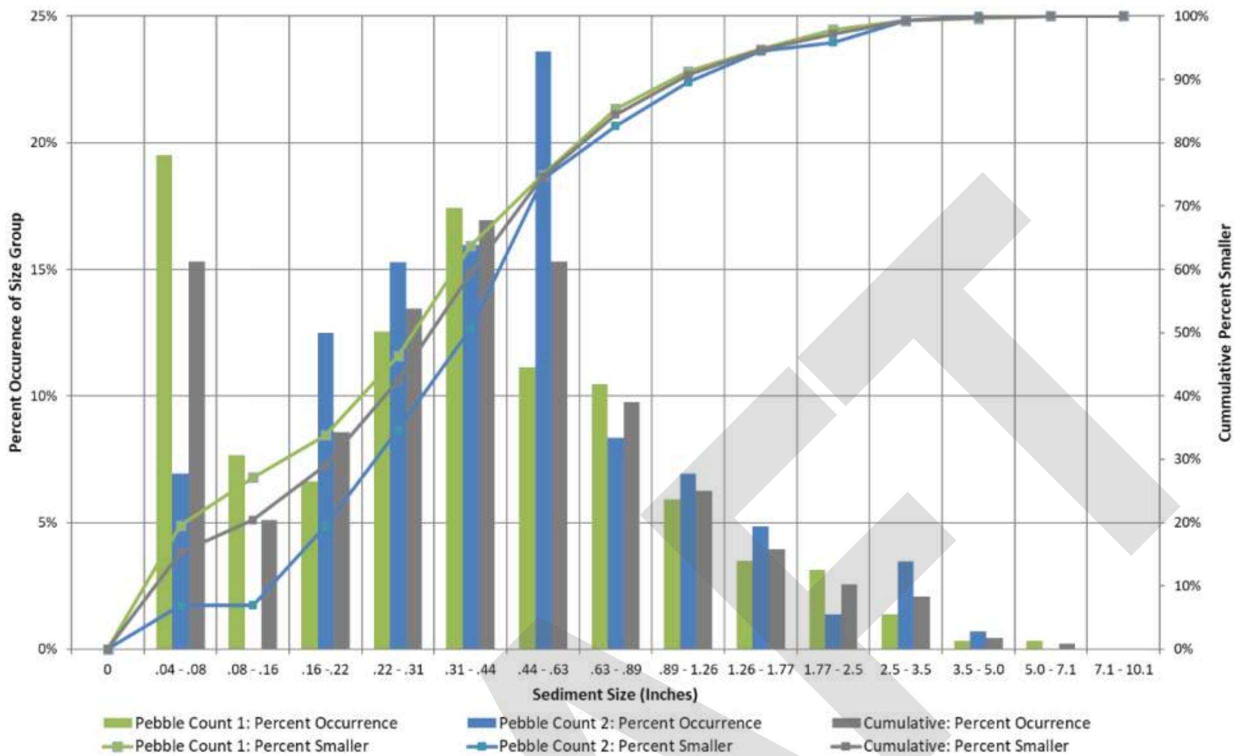

Figure 37: Sediment size distribution

Figure 38: Representation of typical channel substrate

Figure 39: Boulders from road embankment or placed boulders downstream

The channel has deformable step pools formed by small woody debris and cobbles. Downstream of the second pebble count, there are a few non-deformable steps where placed boulders were observed. Drops across each step were quantified as the vertical distance from the crest of the step to the channel elevation downstream of the step (Table 6). The average drop height throughout the reach is 0.6 feet.

Table 6: Deformable step drop heights upstream (water surface to water surface)

Measurement	Drop distance (ft)	Distance from culvert inlet (ft)
1	0.4	50
2	0.3	109
3	0.7	170
4	0.3	234
5	0.3	239
6	0.5	250

Table 7: Deformable step drop heights downstream (water surface to water surface)

Measurement	Drop distance (ft)	Distance from culvert outlet (ft)
7	0.9	20
8	0.7	35
9	0.8	40
10	0.6	50

2.7.4 Vertical Channel Stability

A long channel profile was developed from 2022 WSDOT topographic survey and 2018 LiDAR data (Quantum Spatial, USGS 2018). The LiDAR data used in the analysis are a bare earth raster with 3-foot cell resolution. The long channel profile (Figure 40) describes channel slopes for approximately 2,500 feet upstream and 1,000 feet downstream from the project culvert and includes major features along the tributary. The long profile ends at the downstream end of the project reach as it enters Hood Canal. The downstream extents of the LiDAR data begin at Hood Canal at an elevation of 0 feet NAVD88. The channel extends up from Hood Canal to 1,500 feet upstream of the crossing at a consistent average slope of 7.4 percent. The WSDOT 2022 topographic survey extents are included within this 7.4 percent slope, which is based on the LiDAR data. Upstream of the 7.4 percent average slope, the channel continues at a slope of 10.3 percent for approximately 500 feet and then increases again to 21.3 percent for the next 500 feet of the LiDAR survey. For the remaining 500 feet upstream of the LiDAR survey depicted in Figure 40, the slope decreases back to 10.3 percent. Throughout the entirety of the long profile UNT to Hood Canal meanders through a forested canopy.

Within the project reach, localized signs of scour and deposition were observed. Throughout the upstream and downstream reaches, sediment deposits upstream of LWM were also observed, indicating a supply of sediment. These gravel and sand deposits along with local scour show that the sediment supply appears to be in equilibrium within the channel. An upstream barrier at WDFW ID 600386 approximately 600 feet upstream of the culvert inlet at WDFW ID 996811 has the potential to limit sediment influx on a larger scale. Sediment deposits upstream of LWM or along channel bends generally consisted of fines and gravels, and cobbles were scattered throughout riffle sections. Deposition was also observed immediately upstream of a constructed dam, which occurs approximately 130 feet downstream of the culvert outlet and past the confluence with UNT to Hood Canal (from WDFW site ID 991612). Within the channel, the banks vary on average from 1 to 2 feet high throughout the upstream and downstream reaches, which indicates that local bank erosion is occurring. Between the channel and valley walls, site observations indicate that the channel has previously migrated within the valley. These migrations have left behind benches and terraces that no longer are activated at the highest flow events. Heavily eroded undercut banks were observed in one location immediately downstream of the culvert outlet. This is typical of outlets from undersized culverts and is more indicative of energy dissipation and high velocities rather than reach-scale processes. Pockets of hardened clay deposits were observed in the banks and bed starting approximately 45 feet downstream of the culvert outlet and were observed throughout the extents of the surveyed downstream reach. These exposed pockets of clay may limit the ability of the channel to erode. These clay pockets were identified by the geotechnical team as glacial till; see Section 7 for additional details.

On a large scale, the long profile shows similar gradients upstream and downstream of the crossing with no vertical separation, indicating a low likelihood for a headcut to propagate upstream. If the downstream diversion structure is removed, there is potential for the stream's vertical profile to adjust through the project area. Additional information on how the channel bed characteristics affect degradation will be provided in the Geotechnical Memorandum.

A projected equilibrium slope in Section 7.2 is based off the Hood Canal as a base point and grade control downstream. It indicates that the channel could degrade up to 4 feet, but the exposed glacial till in the downstream reach may make the channel more resistant to vertical bed adjustments. Aggradation is not anticipated. Additional data in the Geotechnical Memorandum is needed to further assess the validity of the Hood Canal base point. See Section 7.2 for a more specific discussion of quantifying long-term aggradation and degradation potential.

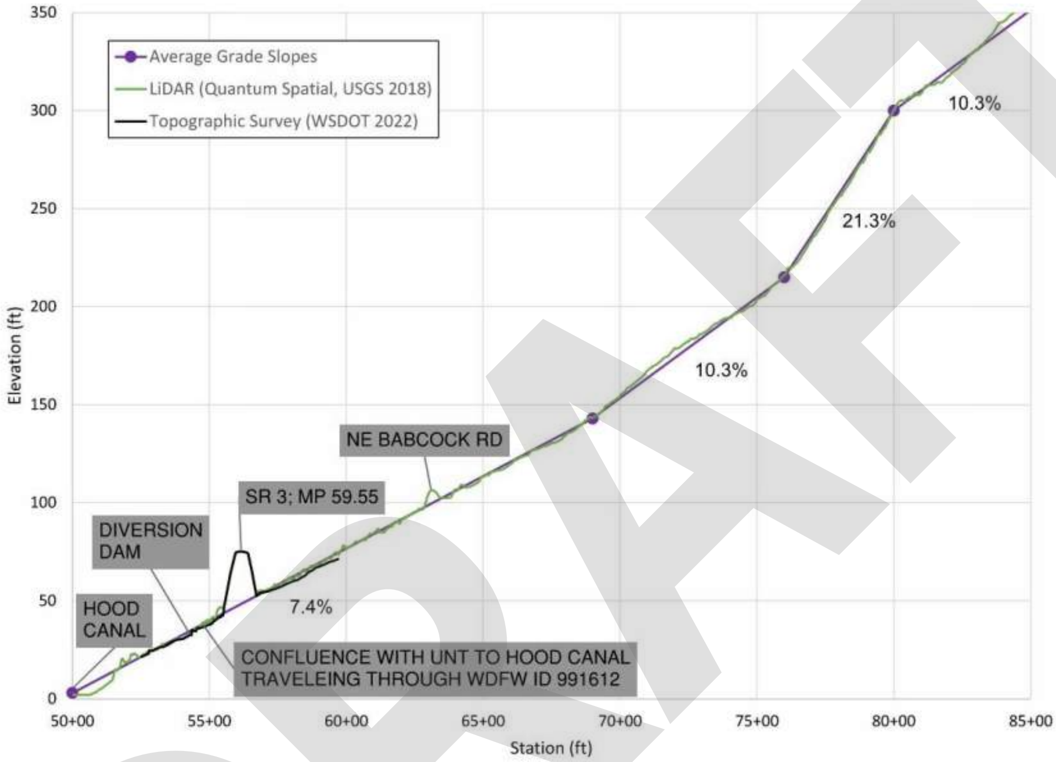

Figure 40: Watershed-scale longitudinal profile

2.7.5 Channel Migration

Channel migration was assessed using historical imagery, modeling results, and field observations. The historical aerial imagery gives little information on channel migration near the project site because the channel is in a forested area, making it difficult to determine where the channel is based on aerial photographs. The channel itself cannot be assessed from aerial imagery (USGS 2021) and no channel migration zone delineation information was found for this project site.

There is a risk of lateral migration in relation to the structure. The Geotechnical Memorandum, which is in progress, will provide data to make an assessment on whether the risk of lateral migration is low (this document will be cited once it is received). Site visits and modeling results indicate that it is not likely for the channel to make migrations large enough to affect flow conveyance and geomorphology through the proposed structure. The channel is well defined and steep, and the planform is mostly straight with occasional tight channel bends creating low sinuosity. The banks vary on average from 1 to 2 feet high throughout the upstream and downstream reaches, showing signs of local bank erosion. Gravel and sand deposits upstream of small and large woody debris were present, indicating signs of deposition. Channel-forming flows could result in bank erosion, sediment deposition, and recruitment of woody material that change the flow path. The channel could migrate laterally within its valley at channel-forming flow events but is unlikely to migrate beyond its meander width (see Section 4.1.1) to affect flow conveyance. Based on modeling results, water does not reach the floodplain and flows are maintained with the channel banks at all flow events. Observations of a confined, narrow channel confirm the modeling results that flow does not activate the floodplains. No high water marks were observed in the field.

The Stage IV classification of the channel evolution model is in line with these potential channel processes. The potential for channel migration to extend beyond the existing floodplains and valley walls is low given the confined nature of the channel. Valley measurements, from between the valley toe and top, were taken at four of the BFW measurement locations (see Appendix B for measurement details) and varied from 20.5 to 34.0 feet, resulting in an average valley width of 25.0 feet. The channel and floodplain can move within this valley width, but likely will not expand beyond this valley. In addition to field measurements, a meander belt analysis was conducted and is described in Section 4.1.1.

3 Hydrology and Peak Flow Estimates

USGS regression equations (Mastin et al. 2016) for Region 3 were used to estimate peak flows in UNT to Hood Canal. These equations were deemed most appropriate because the watershed is less than 5 percent developed and no previous hydrology reports were developed for this basin. Inputs to the regression equation include drainage area and mean annual precipitation. UNT to Hood Canal has a drainage area of 0.1 square mile with a mean annual precipitation of 34.3 inches (PRISM Climate Group 2019). The basin was delineated from LiDAR data acquired from the DNR LiDAR Portal (Quantum Spatial, USGS 2018) using Arc Hydro basin delineation tools. The Arc Hydro results and their correlation with topographic data, stormwater network, and existing culverts were inspected to confirm the final delineation. StreamStats was used to delineate the basin to check for low flows during the summer. No information was available regarding low flow conditions in summer in UNT to Hood Canal (USGS 2016).

The basin to the south for UNT to Hood Canal draining to WDFW site ID 991612 was also delineated because it was modeled with UNT to Hood Canal flowing though WDFW site ID 996811 (Figure 41). Sixty feet downstream of the project culvert outlet, the UNT to Hood Canal that crosses through WDFW site ID 991612 joins with UNT to Hood Canal flowing through WDFW site ID 996811. Each stream does not affect the hydraulics of the other through backwater influences or high velocities at the culvert outlets, but they share a hydraulic connection downstream of the confluence. Therefore, the hydrologic outputs of the southern basin draining to WDFW site ID 991612 are included in this PHD Report. The UNT to Hood Canal, the southern basin draining to WDFW site ID 991612, has a drainage area of 0.43 square mile and mean annual precipitation of 35.4 inches.

WSDOT recognizes climate resilience as a component of the integrity of its structures and approaches the design of bridges and buried structures through a risk-based assessment beyond the design criteria. The largest risk to bridges and buried structures will come from increases in flow and/or sea level rise. The goal of fish passage projects is to maintain natural channel processes through the life of the structure and to maintain passability for all expected life stages and species in a system.

WSDOT evaluates crossings using the mean percent change in 100-year flood flows from the WDFW Future Projections for Climate-Adapted Culvert Design program. All sites consider the projected 2080 percent increase throughout the design of the structure. Appendix G contains the projected increase information for the project site. The design flow for the crossing is 6.3 cubic feet per second (cfs) at the 100-year storm event. The projected increase for the 2080 100-year flow is 44.1 percent, yielding a projected 2080 100-year flow of 9.1 cfs.

Peak flows for UNT to Hood Canal at SR 3 are shown in Table 8.

Table 8: Peak flows for UNT to Hood Canal at SR 3

Mean recurrence interval (MRI) (years)	WDFW site ID 996811 USGS regression equation (Region 3) (cfs)	Predicted interval lower to upper 90% confidence level (cfs) (WDFW site ID 996811)	WDFW ID 991612 USGS regression equation (Region 3) (cfs)	Predicted interval, lower to upper 90% confidence level (cfs) (WDFW site ID 991612)
2	**1.8**	**0.9–3.7**	6.9	3.4–13.9
10	**2.9**	**1.7–7.8**	14.1	6.7–29.5
25	**4.7**	**2.1–10.4**	18.0	8.2–39.4
50	**5.5**	**2.4–12.6**	20.8	9.2–47.0
100	**6.3**	**2.7–14.7**	24.0	10.4–55.3
500	**8.2**	**3.2–20.9**	31.5	12.6–79.0
Projected 2080 100	**9.1**	**NA**	34.6	NA

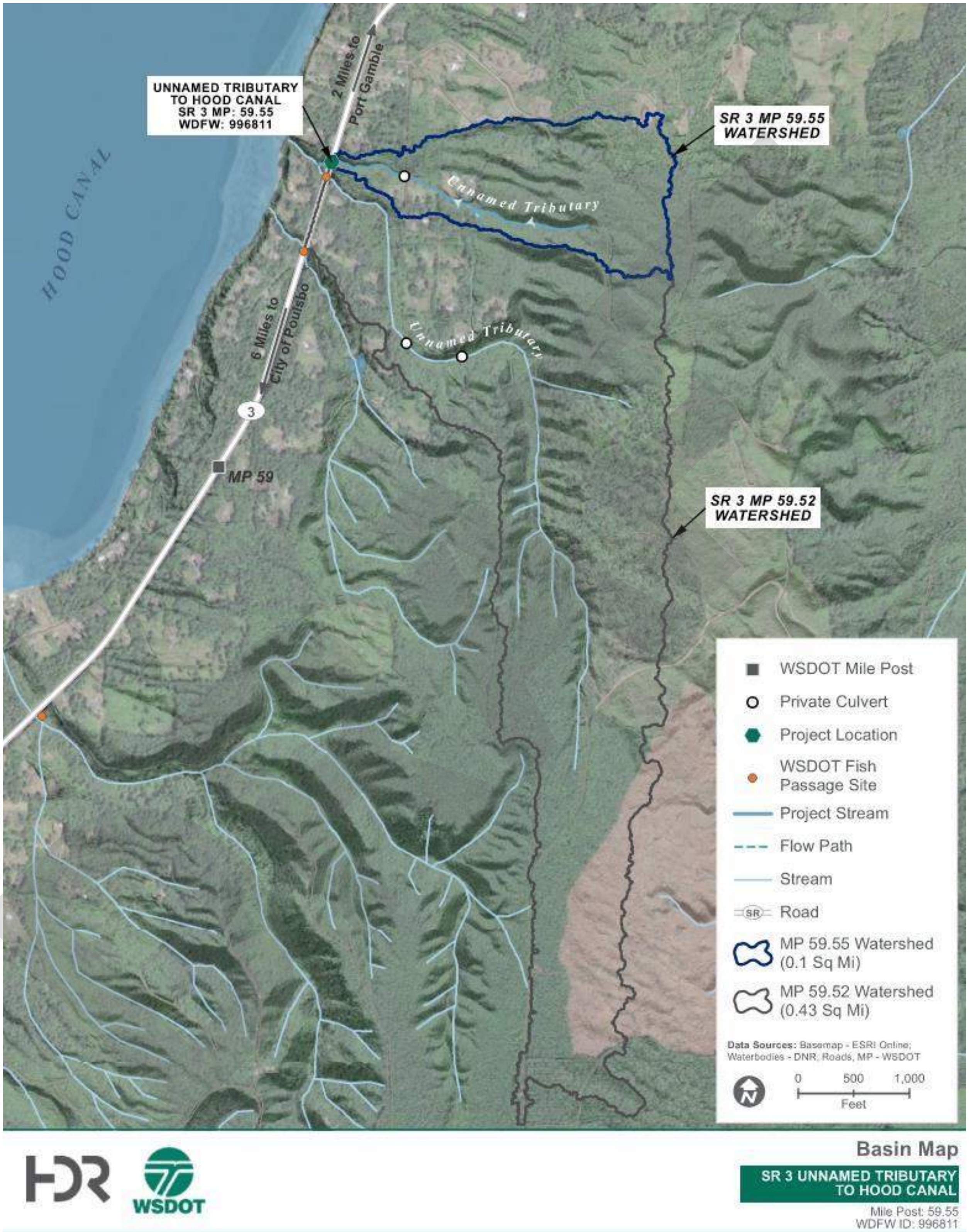

Figure 41: Basin Map Displaying Comparison of MP 59.52 and MP 59.55 Watersheds

4 Water Crossing Design

This section describes the water crossing design developed for SR 3 MP 59.55 UNT to Hood Canal, including channel design, minimum hydraulic opening, and streambed design.

4.1 Channel Design

This section describes the channel design developed for UNT to Hood Canal at SR 3 MP 59.55.

Variability in the cross-sectional shape is proposed because of the steep roadway fill located within the vicinity of the project crossing. Without transition grading, the proposed cross section would require a large amount of cut before meeting existing grade. Transitional cross-sectional shapes are proposed to limit cut and to use the existing channel shape within the design.

4.1.1 Channel Planform and Shape

The proposed channel shape was determined by comparing the shape to the existing channel cross-section shape within the reference reach. Modeling results within the reference reach were compared to the design channel shape to determine if the design shape matched natural conditions within the reach. Velocities and depths within the design channel shape closely matched those through the reference reach, so the proposed cross section was determined to be suitable for design. The comparison of 2-year and 100-year flow event hydraulic results within the reference reach and the proposed design section are detailed in Table 9 to display how the proposed cross section will function similarly to the reference reach. Further hydraulic results are presented in Section 5.2 and 5.4.

Table 9: Comparison of reference reach and proposed design cross section hydraulic results

Hydraulic Parameter	2-year flow event		100-year flow event	
	Reference reach, STA 5+79	Proposed cross section, STA 3+63	Reference reach, STA 5+79	Proposed cross section, STA 3+63
Top width (ft)	3.2	3.0	4.0	4.5
Maximum depth (ft)	0.4	0.4	0.7	0.8
Velocity (ft/s)	1.5	1.5	2.5	2.7

The proposed design at 2-year modeled event has a width to depth ratio of 7:1 which is similar to the reference reach width to depth ratio of 8.5:1. The proposed channel (Figure 43) closely matches the existing channel shape, but as shown in the 100-year flow event top width comparison from 4.0 feet to 4.5 feet, the proposed channel cannot match the existing channel shape exactly without steepening the banks. The proposed channel banks have a 2:1 slope, which is the maximum constructible slope without engineered stabilization techniques. To compensate for the proposed banks not being steep enough to match existing conditions, the channel bed width (toe-to-toe) was shortened to a minimum practicable width of 1.5 feet. The topographic survey indicates that the bed width in the reference reach is approximately 2 feet on average. The proposed channel therefore has a slightly narrower bed width, compensated with a slightly wider bank width, compared to the existing channel shape, causing the slight difference in width to depth ratio between the design channel shape and the reference reach channel shape. Over time, the proposed channel may adjust to have steeper slopes and match the existing cross-sectional shape. It was also considered to widen the toes of the design cross section to more closely match the bottom width of the reference reach; however, this would widen the top width and decrease depths in the design cross section to below 0.4 foot, resulting in shallower depths at low fish passage flows.

Modeled 2-year and 100-year water surface elevations (WSEs) are shown in Figure 42. The 2-year flow event does not reach a floodplain bench within the reference reach; additionally, the 100-year flow event in the reference reach does not reach the floodplain bench. As a result, floodplain benches were not added to the design cross-section shape to match natural channel conditions more closely. In a channel as confined as this one (FUR of 1.3 on average), which does not have flow events that reach the floodplains, adding floodplain benches into the design shape would not mimic the natural conditions through the reference reach. In addition, to be activated at the 2-year flow event, benches would need to be approximately 0.4 foot in height (Table 9). This is not easily constructable and would also decrease depths in the channel at low fish passage flows.

In later stages of the project, a low-flow channel will be added that connects habitat features together so that the project is not a low-flow barrier. The low-flow channel will be as directed by the engineer in the field.

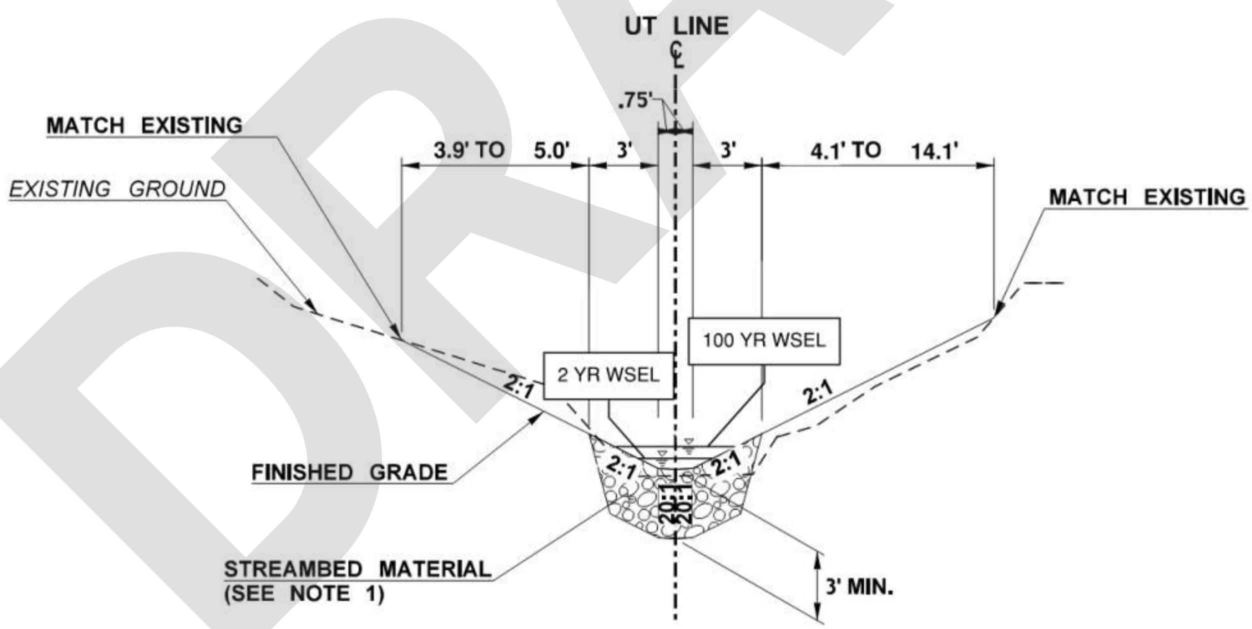

Figure 42: Design cross section

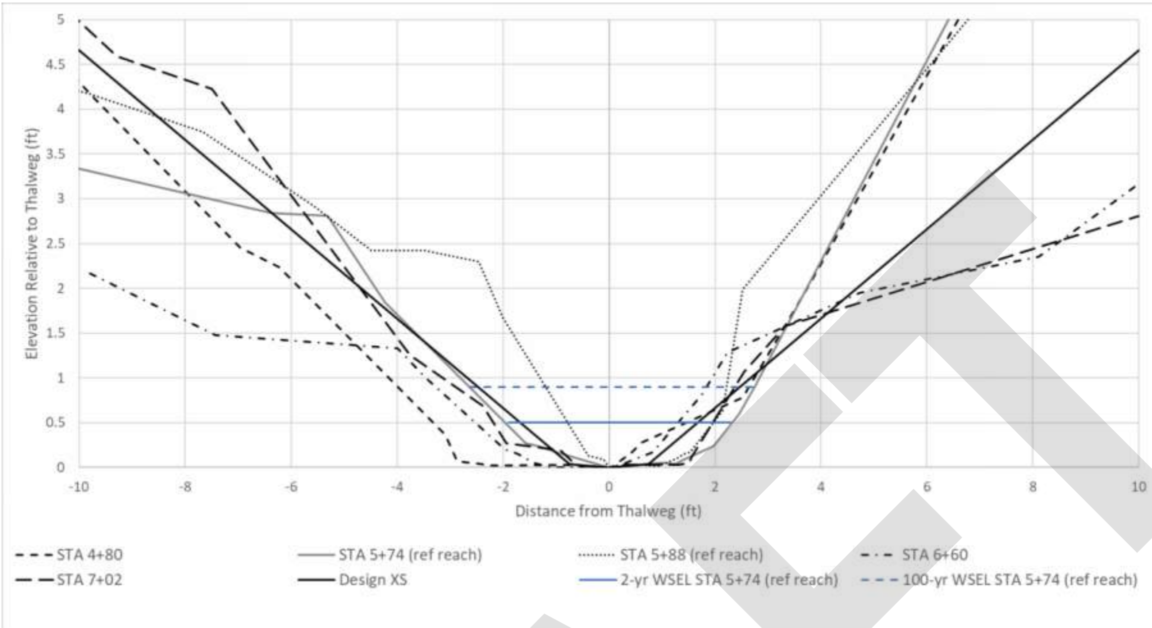

Figure 43: Proposed cross section superimposed with existing survey cross sections

A meander belt analysis was performed because the structure length is more than 10 times its 9-foot width developed from stream simulation criteria. Using the topographic survey, a corridor containing the channel meanders was drawn in plan view along the channel. The meander belt width connects the outer bends of each meander as depicted in Figure 44. The outer bends were identified based on the top-of-bank break lines from the WSDOT topographic survey. The meander belt width was measured at one location downstream between the confluence and the culvert outlet as well as every 50 feet in the upstream reach. The average upstream meander belt width was 14.1 feet and overall varied from 12.2 to 16.7 feet. One downstream measurement of meander belt width was taken and results in a width of 12.1 feet. This measurement was not considered within the analysis because it is heavily influenced by road fill. See further discussion on MHO width in Section 4.2.2.

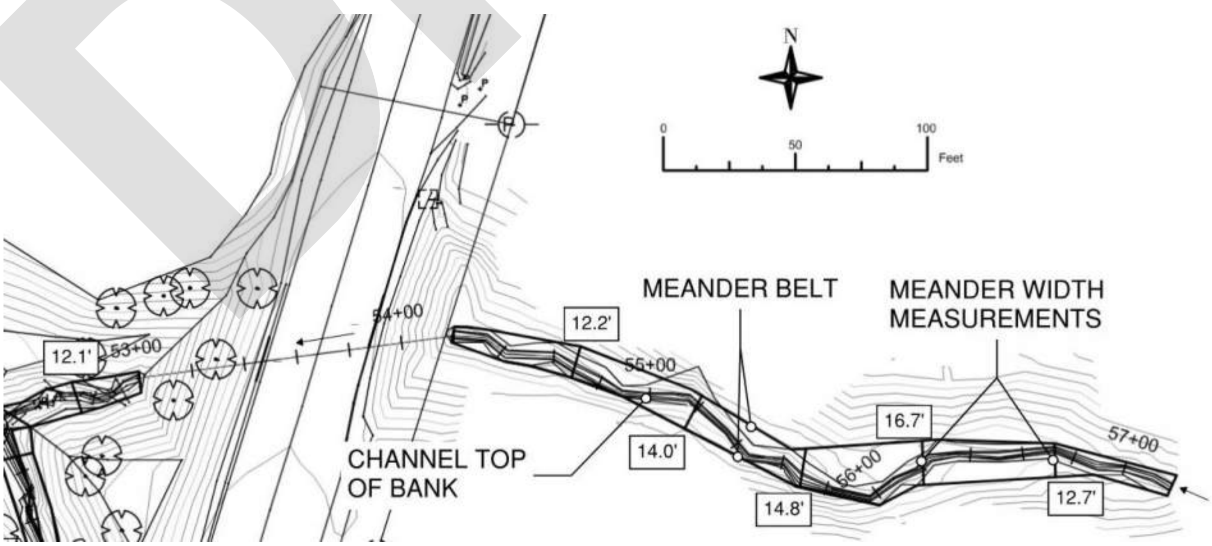

Figure 44: Meander belt analysis

4.1.2 Channel Alignment

The proposed design will primarily follow the alignment of the existing stream and include channel regrading for approximately 146 feet, including tie-in distance. Upstream the proposed grading will tie into the existing channel approximately 20 feet upstream of the existing culvert inlet. Downstream the proposed grading ties into the existing channel 10 feet downstream of the existing culvert outlet.

The proposed channel alignment and grading extents are illustrated in design drawings provided in Appendix D. The main channel width is currently shown straight and centered within the floodplain grading. During future phases of design, the main channel shall meander within the MHO to provide planform variability. This future change may result in a longer stream length, higher sinuosity, lower slopes, higher flow depths, and slower velocities; however, given the steep slopes present within the crossing, these hydraulic changes are anticipated be minimal. These changes will create more favorable hydraulic conditions than those presented within this PHD Report.

4.1.3 Channel Gradient

The WCDG (Barnard et al. 2013) recommends that the proposed culvert bed gradient be not more than 25 percent steeper (slope ratio less than 1.25) than the existing stream gradient upstream of the crossing (WCDG Equation 3.1). The proposed channel gradient is 8.0 percent and the average channel gradient within the total topographic survey extents including both upstream and downstream reaches is 7.0 percent, while the channel gradient through the reference reach upstream is 6.8 percent. The slope ratio of the proposed slope to the reference reach results in a slope ratio of 1.17, and the slope ratio of the proposed slope to the average channel gradient is 1.14. The design gradient meets the slope ratio and best resolves the geologic, geometric, and constructibility constraints of the project site while limiting the impacts to the existing riparian corridor.

Long-term degradation is expected to range from 0 to 4 feet. No large grade breaks or slope discontinuities exist in the immediate vicinity of the project. Refer to Section 7.2 for a more detailed discussion of long-term degradation and aggradation. There are no constraints in the project site to contain the long-term degradation besides the stability of the structure. Long-term aggradation is not expected to occur.

4.2 Minimum Hydraulic Opening

The MHO is defined horizontally by the hydraulic width and the total height is determined by vertical clearance and scour elevation. This section describes the minimum hydraulic width and vertical clearance; for discussion on the scour elevation see Section 7. See Figure 45 for an illustration of the MHO, hydraulic width, freeboard, and maintenance clearance terminology.

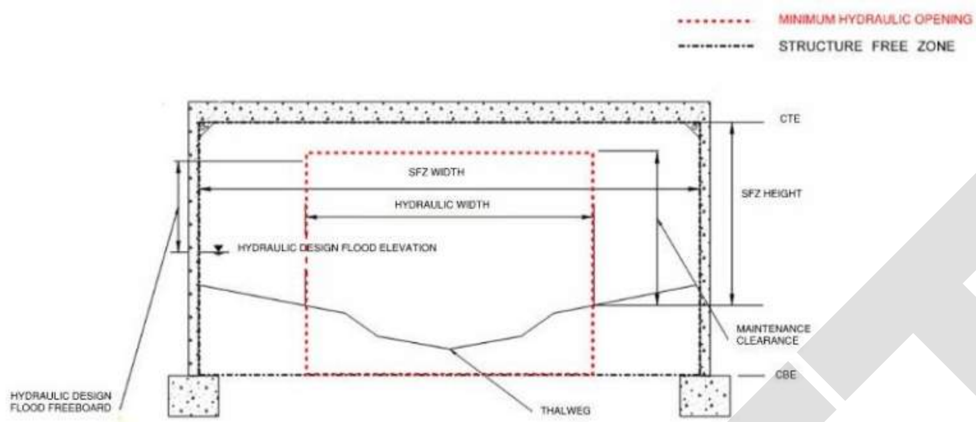

Figure 45: Minimum hydraulic opening illustration

4.2.1 Design Methodology

The proposed fish passage design was developed using the WCDG (Barnard et al. 2013) and the WSDOT *Hydraulics Manual* (WSDOT 2022a). Using the guidance in these two documents, the stream simulation design method was determined to be the most appropriate at this crossing because the BFW is less than 15 feet (refer to Section 2.7.2), the channel is confined (refer to Section 2.7.2.1), and the slope ratio is less than 1.25 (refer to Section 4.1.3). The design was also influenced by the length of the proposed crossing (refer to Section 4.1.2), channel stability (refer to Section 7.2), and channel migration (refer to Section 2.7.5 and 4.1.1).

4.2.2 Hydraulic Width

The starting point for the minimum hydraulic width determination of this WSDOT crossing is Equation 3.2 of the WCDG, rounded up to the nearest whole foot. For this crossing, a minimum hydraulic width of 10 feet was determined to be the minimum starting point.

Further, a meander belt assessment was performed because the stream simulation width of 10 feet is not large enough to allow for the natural channel processes. The meander belt analysis resulted in an average meander width of 14.1 feet as discussed in Section 4.1.2. To accommodate the potential meander of the stream, the structure width was increased to 15 feet. The structure width was not increased to accommodate lateral migration beyond the valley (see Section 7.1 for an assessment of lateral migration risk).

To further confirm this structure width, UNT to Hood Canal flowing though WDFW site ID 996811 was compared to its adjacent stream to the south, UNT to Hood Canal flowing though WDFW site ID 991612. This southern tributary has a basin of 0.4 square mile and a 100-year flow event of nearly 32 cfs and was sized as an 18-foot-wide structure following its meander belt analysis. UNT to Hood Canal flowing though WDFW site ID 996811 has a smaller basin of 0.1 square mile and a 100-year flow event of less than 7 cfs. Therefore, it is expected that the structure width to accommodate UNT to Hood Canal flowing though WDFW site ID 996811 would be smaller than the 18-foot structure width designed for UNT to Hood Canal flowing though WDFW site ID 991612.

The proposed structure width of 15 feet is greater than the minimum 10-foot structure based on the stream simulation equation, and smaller than the maximum 18-foot structure width based on the meander belt analysis of the stream to the south. The proposed width of 15 feet also accommodates a 2.5 factor of safety over the BFW measurement of 6.0 feet (2.7.2), and a 4.0 factor of safety over the 2-year top width average measurement of 3.7 feet (Section 2.7.2.1). The width also assists with stability of the proposed step-pools (section 4.3.1) by allowing room for channel adjustments and thalweg shifts.

Based on the factors described above, a minimum hydraulic width of 15 feet was determined to be necessary to allow for natural processes to occur under current flow conditions. The projected 2080 100-year flow event was evaluated. Table 10 compares the velocities of the 100-year and projected 2080 100-year events.

Table 10: Velocity comparison for 15-foot structure

Location	100-year velocity (ft/s)	Projected 2080 100-year velocity (ft/s)
Reference reach (STA 5+79)	2.5	2.9
Reference reach (STA 5+51)	2.1	2.3
Upstream of structure (STA 4+29)	2.7	3.1
Through structure (STA 3+63)	2.7	3.1
Downstream of structure (STA 2+90)	2.7	3.0

No size increase was determined to be necessary to accommodate climate change. For detailed proposed condition hydraulic results see Section 5.4.

4.2.3 Vertical Clearance

The vertical clearance under a structure is made up of two considerations: freeboard and maintenance clearance. Both are discussed below, and results are summarized in Table 11.

The minimum required freeboard at the project location, based on BFW, is 1 foot above the 100-year WSE (Barnard et al. 2013, WSDOT 2022a).

WSDOT is incorporating climate resilience in freeboard, where practicable, and has evaluated freeboard at both the 100-year WSE and the projected 2080 100-year WSE. The WSE is projected to increase by 0.1 foot for the 2080 projected 100-year flow rate. The minimum required freeboard at this site will be applied above the projected 2080 100-year WSE to accommodate climate resilience.

The second vertical clearance consideration is maintenance clearance. WSDOT HQ Hydraulics determines a required maintenance clearance if a height is required to maintain habitat elements, such as boulders or LWM. If there are no habitat elements requiring maintenance clearance to maintain, the maintenance clearance is only a recommendation by WSDOT HQ Hydraulics, and the region determines the maintenance clearance required.

The channel complexity features in Section 4.3.2 do not include elements of significant size and will not need to be maintained with machinery. If it is practicable to do so, a minimum maintenance clearance of 6 feet is recommended for maintenance and monitoring purposes but generally is not a hydraulic requirement. Maintenance clearance is measured from the highest streambed ground elevation within the horizontal limits of the minimum hydraulic width.

At this location it is practical to provide a minimum clearance of 6 feet because of the large fill embankment on SR 3; further, the maintenance clearance is required at this crossing because the required 1 foot of freeboard on this crossing would not accommodate the full 15-foot structure width and would accommodate a structure width of only approximately 10 feet. Additionally, the maintenance clearance is required at this crossing because of the step-pool design within the structure, which may require infrequent maintenance to maintain its functionality over the design life of the structure.

Table 11: Vertical clearance summary

Parameter	Downstream face of structure	Upstream face of structure
Station	3+11	4+08
Thalweg elevation (ft)	44.0	51.6
Highest streambed ground elevation within hydraulic width (ft)	48.2	55.8
100-year WSE (ft)	44.9	52.4
2080 100-year WSE (ft)	45.0	52.5
Required freeboard (ft)	1.0	1.0
Required maintenance clearance (ft)	6.0	6.0
Required minimum low chord, 100-year WSE + freeboard (ft)	45.9	53.4
Required minimum low chord, 2080 100-year WSE + freeboard (ft)	46.0	53.5
Required minimum low chord, highest streambed ground elevation within hydraulic width + maintenance clearance (ft)	54.2	61.8
Required minimum low chord based on 1 foot of freeboard (ft)	**46.0**	**53.5**
Required minimum low chord (ft)	**54.2**	**61.8**

4.2.3.1 Past Maintenance Records

WSDOT Area 2 Maintenance was contacted to determine whether there are ongoing maintenance problems at the existing structure because of LWM racking at the inlet or sedimentation. The maintenance representative indicated that there was no record of LWM blockage and/or removal or sediment removal at this crossing.

4.2.3.2 Wood and Sediment Supply

The potential for LWM to be transported through the reach is moderate. A large amount of woody material is available for recruitment and could be transported through the proposed reach during high flows; however, the relatively small size of the channel will limit the mobility of the wood. From historical figures the watershed has been used for logging purposes and has been rotationally clear cut over the past century (USGS 2021). The watershed is predominantly dense forest.

The sediment supply at the stream location is discussed in Sections 2.3 and 2.7 and aggradation is not expected to be significant in magnitude (refer to Section 7.2). LWM will increase the potential for localized aggradation by trapping sediment (refer to Section 2.6.4).

4.2.4 Hydraulic Length

A minimum hydraulic width of 15 feet is recommended up to a maximum hydraulic length of 150 feet. If the hydraulic length is increased beyond 150 feet, the hydraulic width and vertical clearance will need to be reevaluated.

4.2.5 Future Corridor Plans

There are currently no long-term plans to improve SR 3 through this corridor.

4.2.6 Structure Type

No structure type has been recommended by WSDOT HQ Hydraulics. The layout and structure type will be determined at later project phases.

4.3 Streambed Design

This section describes the streambed design developed for UNT to Hood Canal at SR 3 MP 59.55.

4.3.1 Bed Material

For sizing streambed material, WSDOT uses the modified critical shear stress method for channels under 4 percent slope and the unit discharge method for slopes steeper than 4 percent. UNT to Hood Canal is steeper than 4 percent and, as a result, the unit discharge method was used. The proposed bed material gradation was created using standard WSDOT specification material to mimic the gradation documented in the pebble count as closely as possible. The proposed mix will consist of 90 percent streambed sediment and 10 percent 8-inch cobbles. This provides the closest gradation to that observed throughout UNT to Hood Canal using WSDOT standard materials (WSDOT 2022b). When comparing the WSDOT streambed sediment alone the D_{50} is not within 20 percent of the observed D_{50}; this is because the observed sediment in the stream is smaller than WSDOT streambed sediment gradation, which is the smallest WSDOT standard streambed material size. Because of the presence of 10 percent 8-inch cobble in the proposed streambed mix, compared to only WSDOT streambed sediment, the D_{50} increases from 0.7 to 0.8, which also is not within 20 percent of the observed D_{50}.

To assess streambed mobility for existing and proposed conditions, the unit discharge method was used to calculate a stable D_{84} particle for the 2-year, 100-year, and 2080 100-year flow events (Bathurst 1987). The D_{84} size was calculated with Equation 3.3 and the D_{16}, D_{50}, and D_{100} were calculated from Equations 3.6 through 3.8 in the WCDG (Barnard et al. 2013). The BFW in the equation was based off of modeling data. The calculated D_{84} values were 1.7, 3.9 and 4.9 inches at the 2, 100, and 2080 100-year events. These sizes are the threshold at which the particle is stable, and were compared to the existing and proposed streambed sizes to assess stability. The existing and proposed streambeds have similar mobility. The D_{100} particle is stable at all events for existing and proposed conditions. The D_{16}, D_{50}, and D_{84} are all mobilized for both existing and proposed conditions as depicted in Table 12, except for the proposed D_{84} at the 2-year event. Sediment mobilized through the reach is likely replaced from the available sediment supply upstream.

The observed pebble count distribution (Section 2.7.3) consists of approximately 15 percent sand particles. While the proposed mix specifies about 25 percent sand particles which, when mobilized, may affect the stability of larger particles, it is expected that any sand or particles that mobilize will be replaced from the available sediment supply upstream.

Table 12: Observed and proposed streambed material and mobility

Particle size	Existing				Proposed			
	Diameter (in)	Mobility			Diameter (in)	Mobility		
		2 yr	100 yr	100 yr (2080)		2 yr	100 yr	100 yr (2080)
$\mathbf{D_{16}}$	0.1	Mobile	Mobile	Mobile	0.02	Mobile	Mobile	Mobile
$\mathbf{D_{50}}$	0.4	Mobile	Mobile	Mobile	0.8	Mobile	Mobile	Mobile
$\mathbf{D_{84}}$	0.9	Mobile	Mobile	Mobile	2.2	Stable	Mobile	Mobile
$\mathbf{D_{100}}$	7.1	Stable	Stable	Stable	8.0	Stable	Stable	Stable

Each species of fish anticipated to be in UNT to Hood Canal will be capable of using the proposed material for spawning. In steeper reaches like this, steelhead and cutthroat trout juveniles hide behind larger cobbles for foraging opportunities. The 8-inch D_{100} cobble would be suitable for this life stage for steelhead and cutthroat.

Constructed step pools are recommended within the proposed structure. Step-pool design guidance is currently in development. The number and spacing of steps will need to be refined at future stages of design as guidance is developed from WSDOT, and as step pools are incorporated into modeling efforts. The step-pool crests should be created with stable rock. The PHD design shows step pools within the structure at a longitudinal spacing of approximately every 20 feet for this preliminary phase of design; three are incorporated for a bridge structure due to its shorter length (Figure 46) and five are incorporated for a buried structure due to its longer length (Figure 47). The longitudinal spacing is conceptual and based on an average spacing of observed step pools. The average observed step drop height throughout the existing upstream and downstream reaches is 0.6 foot (see Table 6 and Table 7 above). To mimic the gradation of step crests observed on site, these steps would consist of one part streambed sediment and two parts 8-inch cobble mix, resulting in the gradation detailed in Table 13. The stability in the step crests was assessed using the same methodology and values as the proposed streambed material described above. In the step crest, the D_{16} is mobilized at all events, and the D_{50} is mobilized only at the 100-year and 2080 projected 100-year event. The D_{84} and D_{100} are stable at all events.

Table 13: Step crest material and mobility

Particle size	Step crest			
	Diameter (in)	Mobility		
		2 yr	100 yr	100 yr (2080)
$\mathbf{D_{16}}$	0.4	Mobile	Mobile	Mobile
$\mathbf{D_{50}}$	2.2	Stable	Mobile	Mobile
$\mathbf{D_{84}}$	5.6	Stable	Stable	Stable
$\mathbf{D_{100}}$	8.0	Stable	Stable	Stable

4.3.2 Channel Complexity

This section describes the channel complexity of the streambed design developed for UNT to Hood Canal at SR 3 MP 59.55.

4.3.2.1 Design Concept

The proposed channel is designed to mimic existing conditions as much as possible by following natural bends and disturbing only the area necessary to adequately tie into the existing ground. To promote channel complexity LWM will be placed to offer channel-forming features, bank stability, and complexity to enhance fish habitat. The LWM installations will provide structures conducive to creating stream complexity and facilitate geomorphic functions in segments that will have low natural LWM delivery rates while new and impacted riparian areas recover from construction activities related to installation of the new crossings and regrading of the stream channel. Step pools will also increase stream complexity and will encourage the formation of a step-pool morphology and a planform that matches the upstream reach.

LWM, in conjunction with bank-side bioengineering, will also help protect newly constructed banks and will promote long-term bed stability by creating pools, sinuosity, hard points, and channel roughness. Bank-side bioengineering is recommended immediately after construction for bank stability and will require further coordination with the landscape architect during future phases of design.

To promote stream complexity and restore natural function, WSDOT uses the Fox and Bolton (2007) 75th percentile for wood loading targets. This percentile of wood placement is suggested to compensate for cumulative deficits of wood loading due to development. The 75th percentile targets based on 146 feet of regrade and a 97-foot span culvert are 5 key pieces, 17 total LWM pieces, and 57.6 cubic yards of LWM. A conceptual LWM layout developed for this project area is provided in Figure 46 for a proposed bridge and in Figure 47 for a proposed buried structure. LWM will be placed outside the structure and within the grading extents. The bridge conceptual layout proposes 5 key pieces, 28 total pieces, and 14.0 cubic yards of LWM based on 146 feet of regrade and an approximate bridge length of 45 feet. The buried structure conceptual layout proposes 5 key pieces, 19 total pieces, and 11.3 cubic yards of LWM. Volume of LWM was not met for both conceptual designs because there is not enough space in the grading extents to fit enough LWM to meet the Fox and Bolton criteria. Key piece quantity was also not met for both conceptual designs; the design approach is to match what is already existing within the stream. Per Section 2.6.4, LWM ranged from 8 to 16 inches upstream and 10 to 36 inches downstream. The LWM layouts reviewed the LWM present under existing conditions and were designed using this as a reference. Secondly, the toe width of the channel as 1.5 feet does not allow for placement of larger-diameter LWM within the channel. To avoid blocking flow, all wood 12 inches or greater in diameter would be placed on the floodplains instead of directly within the channel.

Mobile LWM guidance will be determined once a structure type has been recommended. The LWM layout is conceptual; further coordination will be needed with review agencies for the detailed design of habitat structures as design progresses.

LWM structures placed in the stream serve as habitat features for fish. The LWM layout for the proposed channel provides habitat complexity; flow refuge; and pools that allow fish to rest, feed, and protect themselves, especially during high flows. For site-specific considerations for the proposed design to improve ecological integrity at the site, refer back to Section 2. Preformed pools are recommended at rootwads interacting with flow. Risk for fish stranding during summer flow conditions is minimal because proposed grading directs flow back to the main channel and does not promote standing pools. Additionally, a low-flow channel will be constructed and directed in the field by the engineer to help minimize stranding during low flows by providing connectivity between the habitat complexity features. At this time, mobility for LWM is not determined and will be assessed for the Final Hydraulic Design (FHD). Anchoring is anticipated until stability calculations are completed. Within the structure, channel-spanning step-pool crests will be used to promote channel complexity. LWM calculations are referenced in Appendix F.

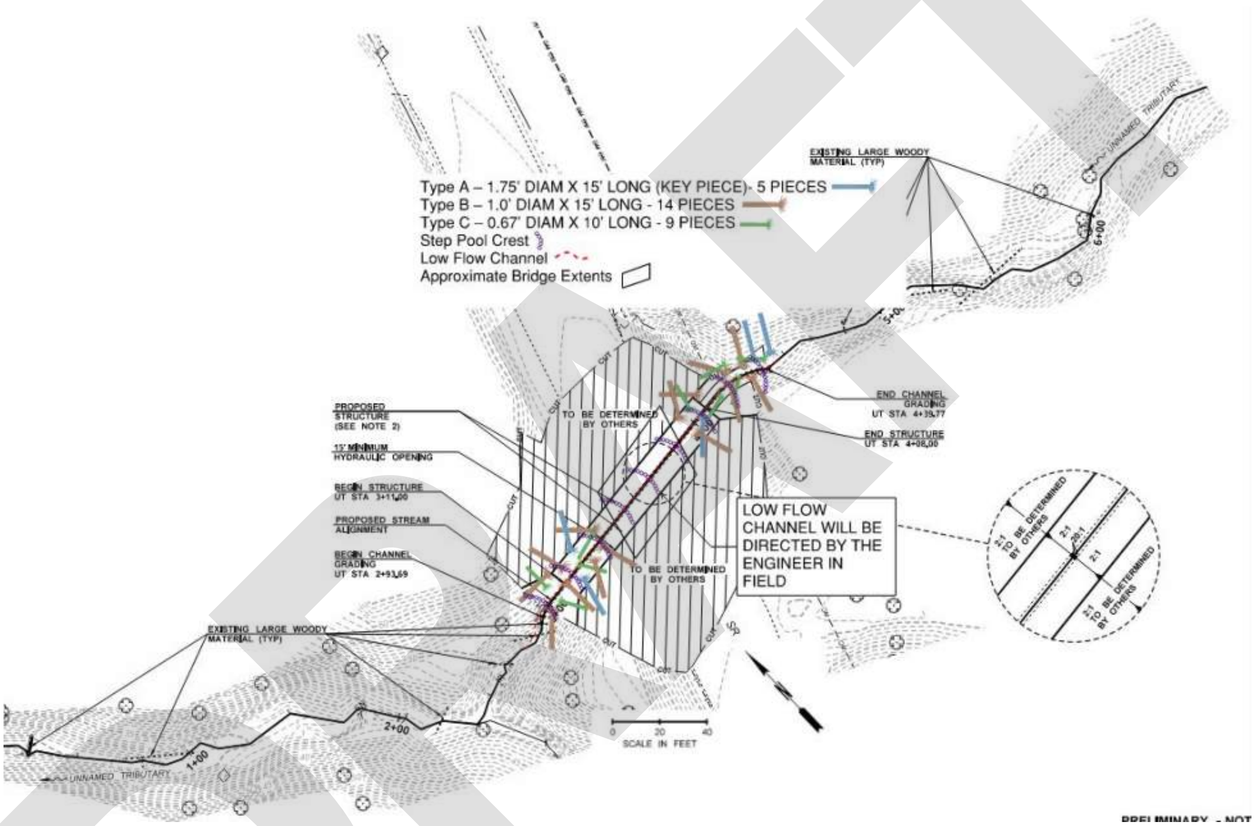

Figure 46: Conceptual layout of habitat complexity for a bridge design

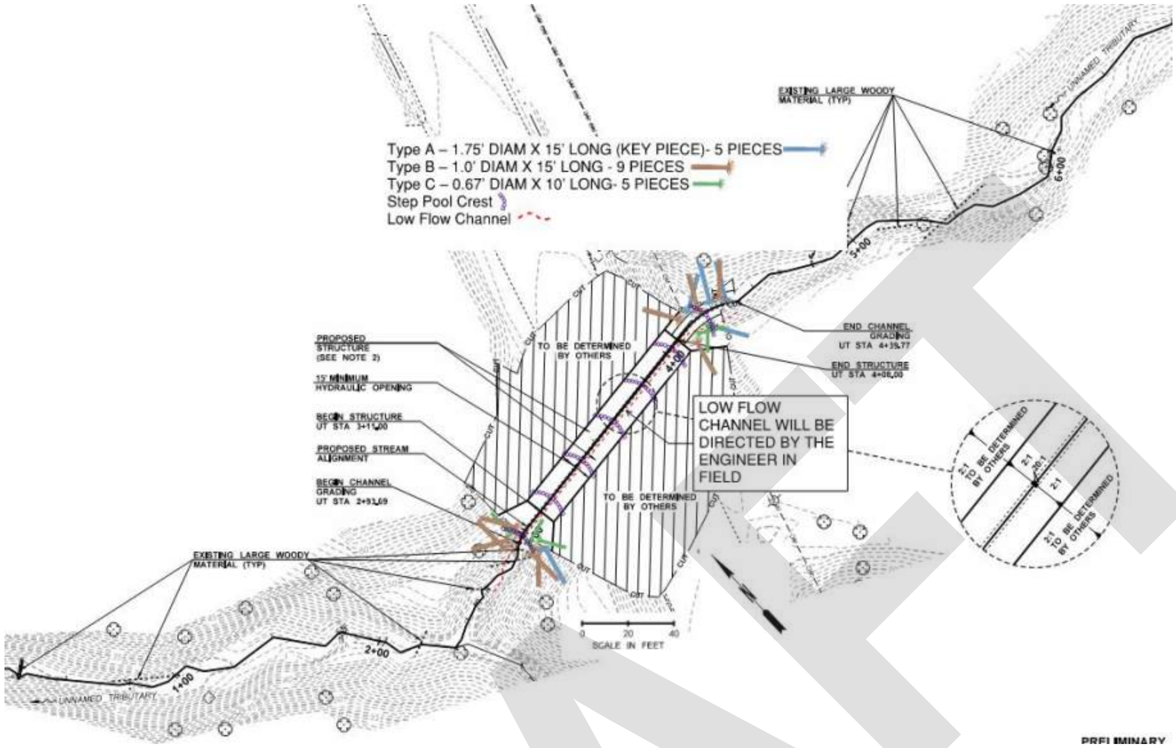

Figure 47: Conceptual layout of habitat complexity for a culvert design

4.3.2.2 Stability Analysis

Large wood stability analysis will be completed at final design.

5 Hydraulic Analysis

The hydraulic analysis of the existing and proposed SR 3 UNT to Hood Canal crossing was performed using the United States Bureau of Reclamation's (USBR's) SRH-2D Version 3.3.1 computer program, a two-dimensional (2D) hydraulic and sediment transport numerical model (USBR 2017). Pre- and post-processing for this model was completed using SMS Version 13.1.17 (Aquaveo 2021).

Two scenarios were analyzed for determining stream characteristics for UNT to Hood Canal with the SRH-2D models: (1) existing conditions with the 2-foot RCP culvert and (2) proposed conditions with the proposed 15-foot hydraulic opening installed.

5.1 Model Development

This section describes the development of the model used for the hydraulic analysis and design.

5.1.1 Topographic and Bathymetric Data

The channel geometry data in the model were obtained from the MicroStation and InRoads files supplied by the WSDOT Project Engineer's Office (PEO), which were developed from topographic surveys performed by WSDOT and received by HDR on March 14, 2022. No LiDAR data were used in the development of the model.

Proposed channel geometry was developed from the proposed grading surface created by HDR and SAEZ Consulting Engineers, Inc (SCE). All survey information is referenced against NAVD88, feet (U.S. Survey) and tied into the WSDOT horizontal project datum using a survey projection supplied by WSDOT.

5.1.2 Model Extent and Computational Mesh

The hydraulic model upstream and downstream extents start and end within the survey data. With a very confined system, LiDAR is not needed to supplement the topographic survey because the detailed survey data provide enough area to adequately model the flow without the water surface touching the edge of the domain. Measured along the channel centerline, the model boundary starts approximately 300 feet upstream of the existing culvert inlet and ends approximately 280 feet downstream of the existing culvert outlet at MP 59.55 (WDFW site ID 996811). The computational mesh elements are a combination of patched (quadrilateral) and paved (triangular) elements, with finer resolution in the channel and larger elements in the floodplain. The existing mesh covers a total area of 82,123 square feet (SF) or 1.9 acres, with 12,873 quadrilateral and 5,024 triangular elements (Figure 48). The proposed mesh covers a total area of 77,365 SF, with 12,976 quadrilateral and 8,993 triangular elements (Figure 49).

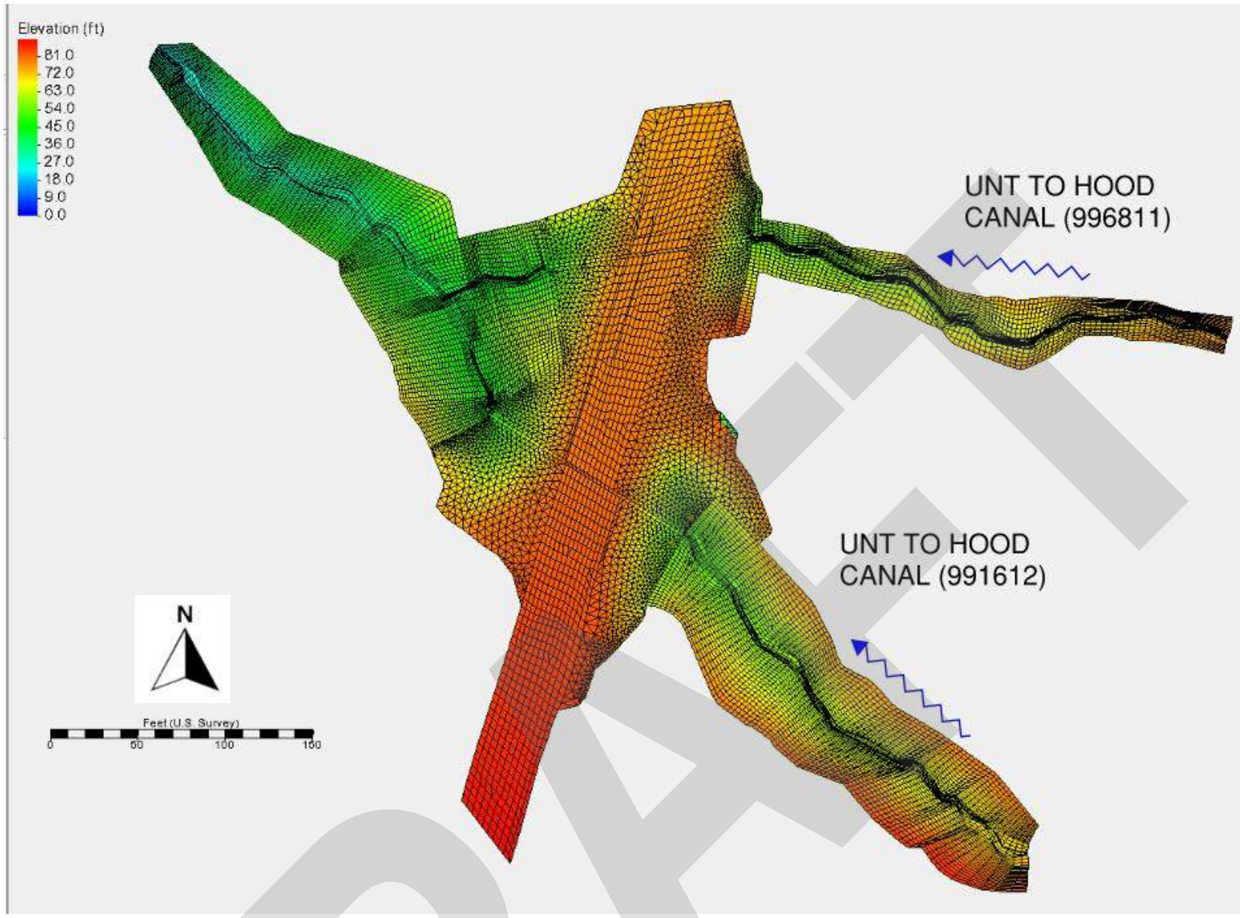

Figure 48: Existing-conditions computational mesh with underlying terrain

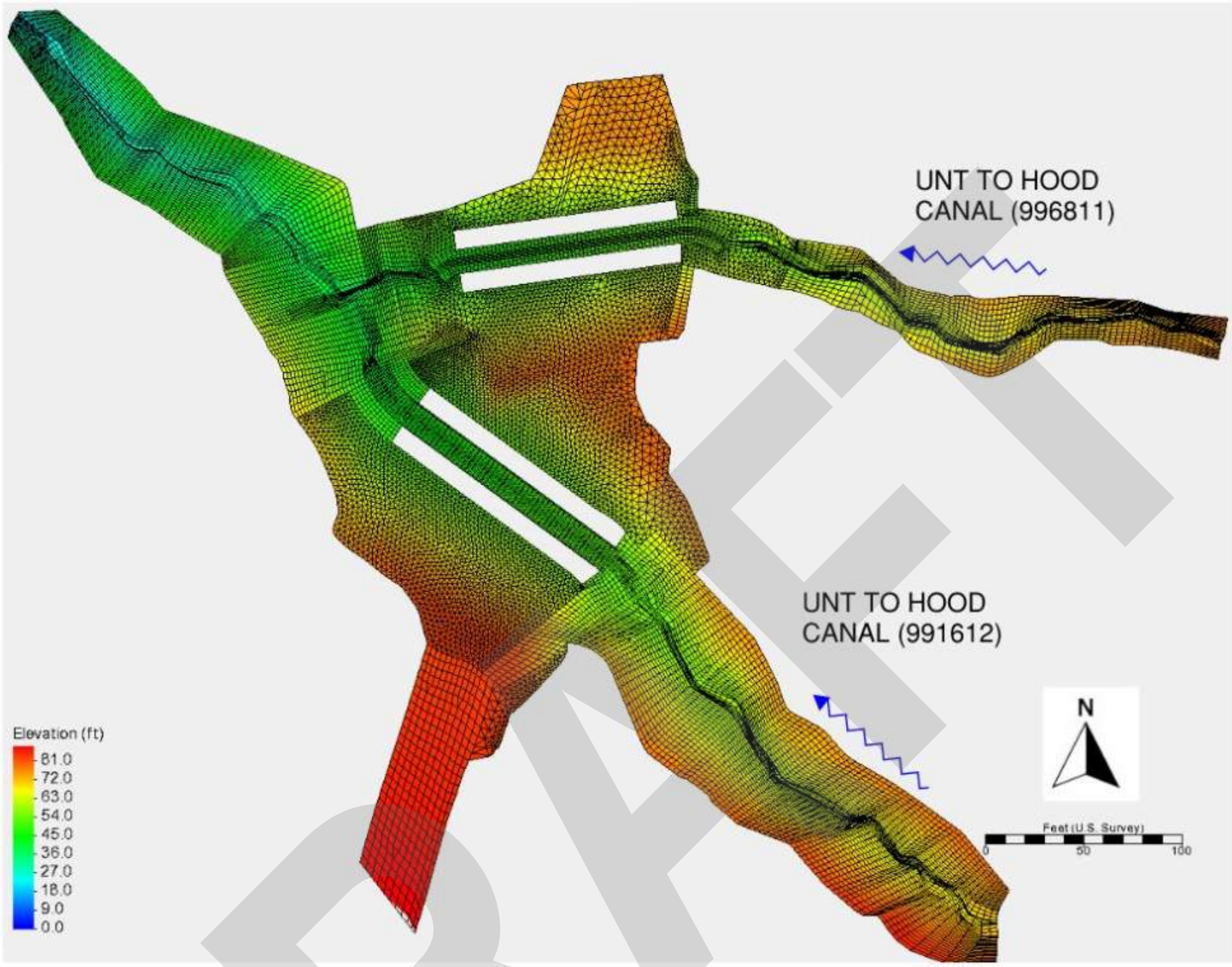

Figure 49: Proposed-conditions computational mesh with underlying terrain

5.1.3 Materials/Roughness

Manning's n values, estimated based on site observations, aerial photography, and standard engineering values (Chow 1959, Yochum et al. 2014, Arcement and Schneider 1989), are summarized below (Table 14). The floodplain roughness of 0.17 was determined with the Arcement and Schneider (1989) quantitative methodology and was referenced against the photo guide from Yochum et al. (2014). The floodplain is characterized by uneven terrain, dense brush, and abundant trees. The channel roughness was also determined with the same methods as the floodplain roughness to come up with a value of 0.11. The channel has abundant woody material forming step-like structures, non-uniform shape, and bed material variability. Though the channel has a steep slope, typical equations that would apply to a stream of greater than 6 percent do not apply because those equations were derived from streams with large cobbles and boulders.

A natural bridge occurs approximately 80 feet upstream of the culvert inlet (WDFW site ID 991612). It is assumed that most of the flow does not go through the orifice to the subsurface flow, but instead goes above the natural bridge. The characteristics of the natural bridge are similar to the floodplain, so this area was given a value of 0.17 to match the floodplain roughness.

Dense LWM with diameters greater than 1 foot that span across and in the channel at the downstream end of UNT to Hood Canal flowing from WDFW site ID 996811 was given a value of 0.2. The roadway was given a low Manning's roughness value of 0.02 because of the uniform nature of the pavement. The roadway over the culvert was also given a roughness value of 0.02.

The only difference between existing (Figure 50) and proposed conditions (Figure 51) is that the channel within the proposed grading limits was given a Manning's roughness value of 0.11. This value was based on a proposed complexity that mimics the existing channel, in the form of step pools in the structure and LWM outside of the structure but within grading limits.

Table 14: Manning's n hydraulic roughness coefficient values used in the SRH-2D model

Material	Manning's n
Dense LWM	0.20
Channel	0.11
Roadway	0.02
Banks/floodplain	0.17
Subsurface flow	0.17

Figure 50: Spatial distribution of existing-conditions roughness values in SRH-2D model

Figure 51: Spatial distribution of proposed-conditions roughness values in SRH-2D model

5.1.4 Boundary Conditions

Model simulations were performed using constant discharges for the 2-year, 100-year, 2080 projected 100-year, and 500-year peak discharges summarized in Section 3. For the culvert at WDFW site ID 996811 flows of 1.8, 6.3, 9.1, and 8.2 cfs were used as the 2-year, 100-year, 2080 100-year, and 500-year discharges, respectively. For the culvert at WDFW site ID 991612 flows of 6.9, 24.0, 34.6, and 31.5 cfs were used as the 2-year, 100-year, 2080 100-year, and 500-year discharges, respectively. External boundary conditions were applied at the upstream and downstream extents of the model domain and remained the same between the existing- and proposed-conditions runs. The two culverts in the model had separate HY-8 inputs as depicted in Figure 52 (WDFW site ID 996811) and Figure 53 (WDFW site ID 991912). Two constant flow rates were specified at the upstream external boundary conditions (one for each of the two UNTs to Hood Canal), while one normal depth rating curve was specified at the downstream boundary (Figure 54). A sensitivity analysis was done with the rating curve to determine that the downstream boundary condition will not affect the hydraulic results at the crossing. The downstream normal depth boundary condition rating curve was developed within SMS using the existing terrain, assuming a downstream slope of 6.0 percent based on topographic survey data. The rating curve also assumed a composite roughness of 0.14. Model simulations were run for a sufficiently long duration until the results stabilized across the model domain. Existing boundary conditions are depicted in Figure 55 and proposed boundary conditions are depicted in Figure 56.

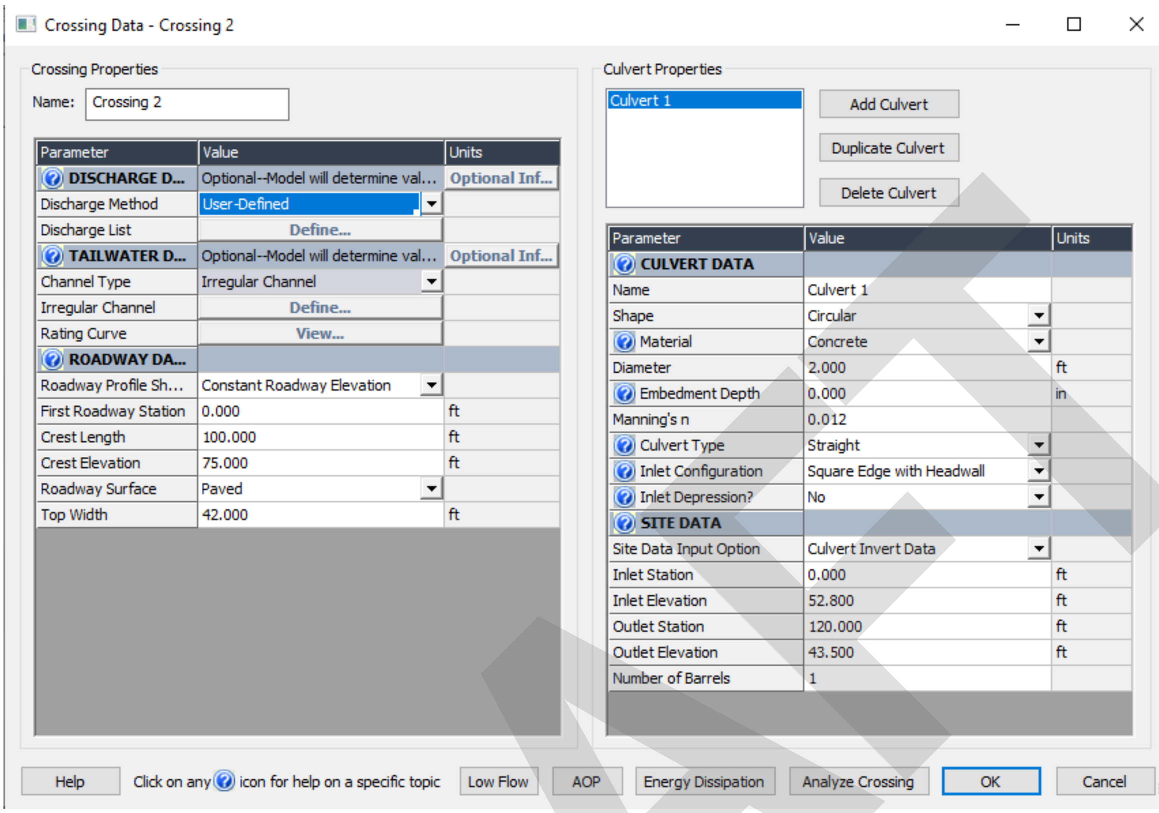

Figure 52: HY-8 culvert parameters: WDFW site ID 996811

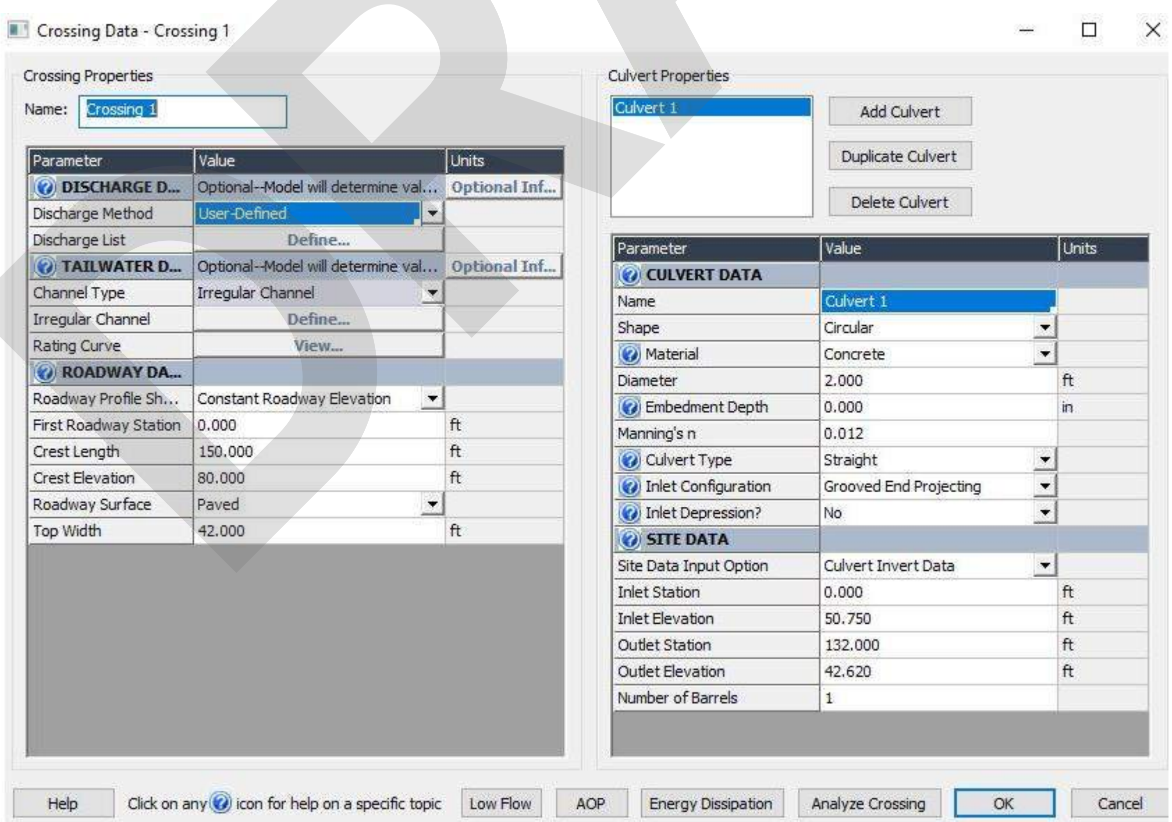

Figure 53: HY-8 culvert parameters: WDFW site ID 991612

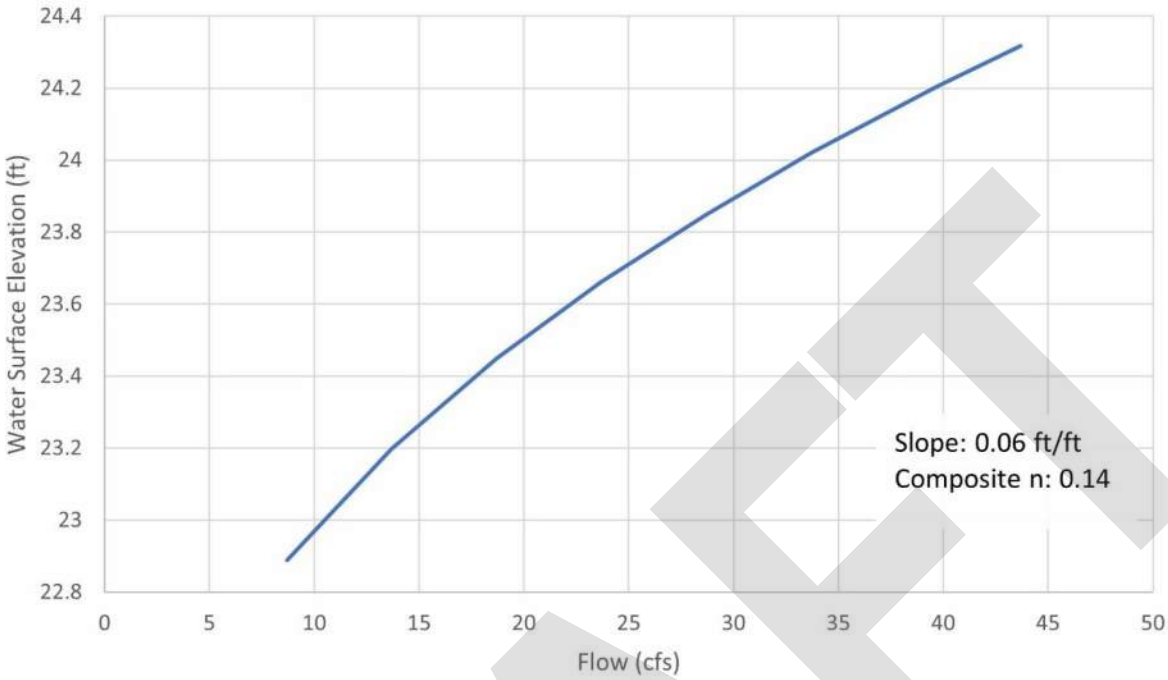

Figure 54: Downstream outflow boundary condition normal depth rating curve

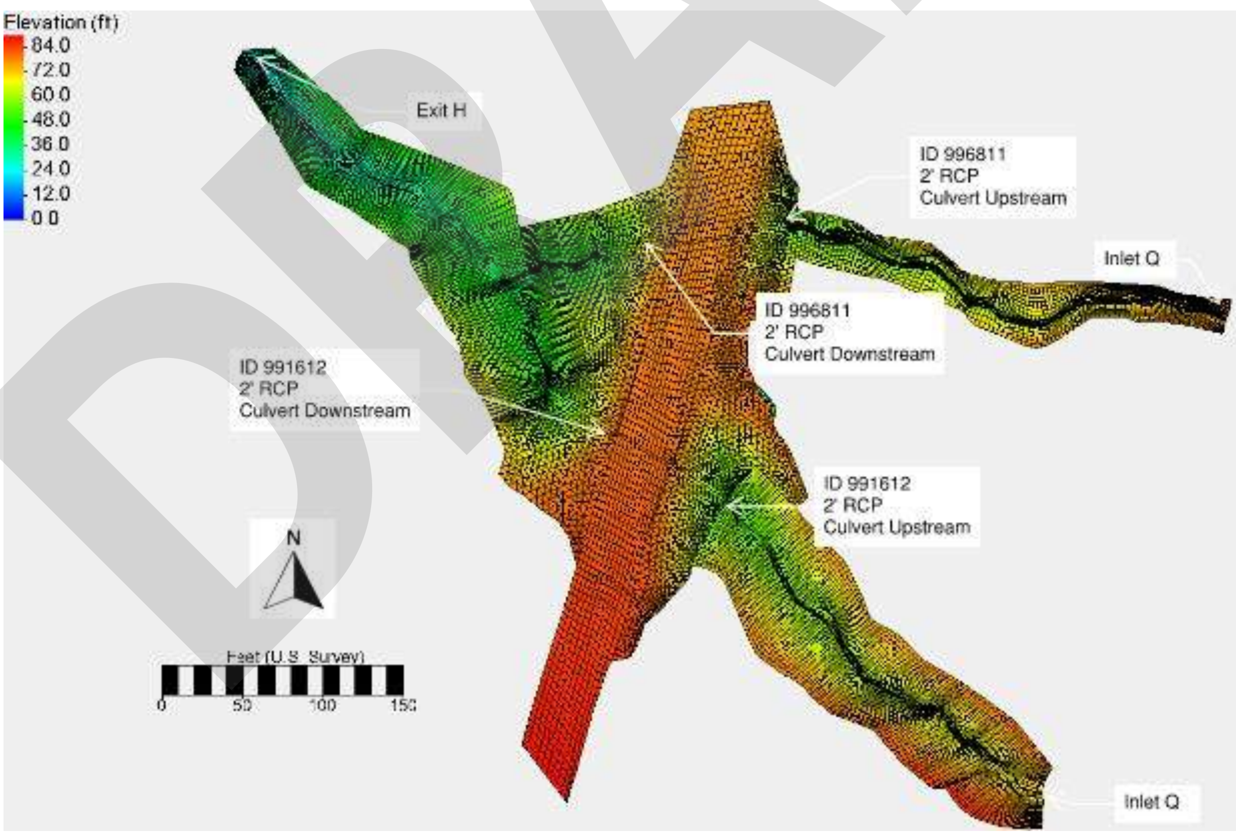

Figure 55: Existing-conditions boundary conditions

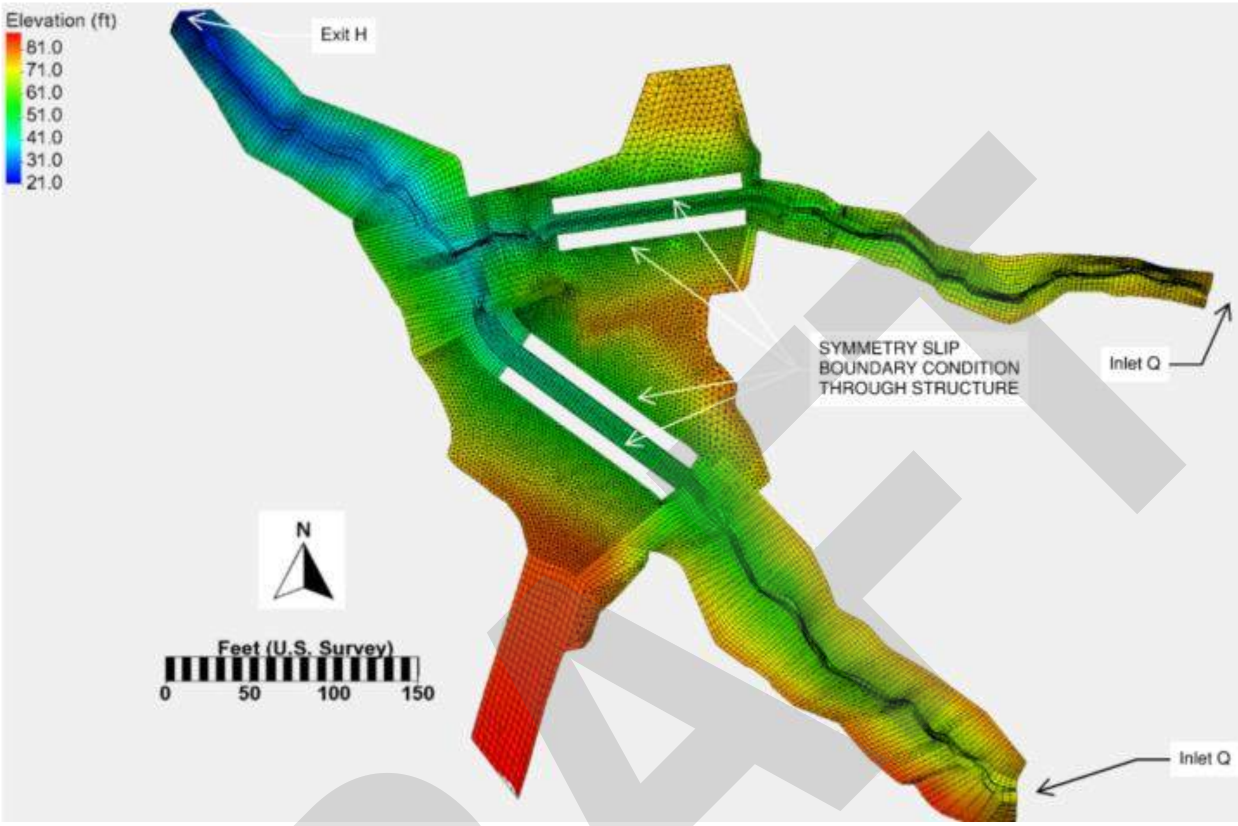

Figure 56: Proposed-conditions boundary conditions

5.1.5 Model Run Controls

Model controls were kept consistent between existing- and proposed-conditions models. All model simulations were run for a sufficiently long duration until the results stabilized across the model domain. Refer to Appendix I for stability plots. The following controls were set at:

- **Start time:** 0.0 hour
- **Time step:** 0.5 second
- **End time:** 1 hour
- **Initial condition:** dry

5.1.6 Model Assumptions and Limitations

The SRH-2D hydraulic model was developed to determine the minimum hydraulic structure opening, establish the proposed structure low chord elevation (and associated freeboard), and characterize hydraulic parameters used to design the crossing. The use of a constant inflow rate is an appropriate assumption to meet the model objectives. Using a constant inflow rate provides a conservative estimate of inundation extents and WSE associated with a given peak flow, which is used to determine the structure size and low chord.

Using the approach described in this study, each scenario is run for a sufficient time to fill storage areas and for WSEs to stabilize until flow upstream equals flow downstream. This modeling method does not account for the attenuation of peak flows between the actual upstream and downstream hydrographs, in particular the storage created by the existing undersized culvert. An unsteady simulation could be used to route a hydrograph through the model to estimate peak flow attenuation for existing and proposed conditions. During an unsteady simulation, the areas upstream of the existing culvert would act as storage and, as a result, the flow downstream of the crossing would likely be less than the current design peak flow event. Estimates of the downstream increases to WSE and flow based on the constant inflow model results may then underestimate the change in downstream flood impacts. An unsteady analysis is outside the current scope of this preliminary study but could be considered at a later stage of design. Therefore, the changes to the peak flow rate downstream of the project cannot be quantified with this approach.

The model results and recommendations in this PHD Report are based on the conditions of the project site and the associated watershed at the time of this study. Any modifications to the site, man-made or natural, could alter the analysis, findings, and recommendations contained herein and could invalidate the analysis, findings, and recommendations. Site conditions, completion of upstream or downstream projects, upstream or downstream land use changes, climate changes, vegetation changes, maintenance practice changes, or other factors may change over time. Additional analysis or updates may be required in the future as a result of these changes.

5.2 Existing Conditions

Hydraulic results were summarized and compared at common locations for the existing- and proposed-conditions simulations (Figure 57). The longitudinal stationing varies in existing versus proposed conditions, but the location of each cross section, denoted by letters, is the same between existing and proposed. The results reporting is summarized for each simulation along the existing and proposed alignment and stationing. Six cross sections were selected to give representation of the geometry on site: two in the reference reach, one upstream and one downstream of the reference reach, one at the roadway centerline, and two between the culvert outlet and confluence.

Cross sections in Figure 57 are used to summarize the hydraulic results for UNT to Hood Canal; see Table 15 for a summary of main channel hydraulic results. Under existing conditions, the culvert is inlet controlled and causes backwater upstream of the inlet during the 100- and 500-year events simulated under SR 3 (Figure 58). Pressure flow in the existing culvert first occurs during the 100-year event. The existing roadway is not overtopped at the project site within the range of flow events modeled.

A typical section with WSEs is depicted in Figure 59; all cross sections are provided in Appendix H. The WSEs shown within the cross section do not reflect the BFW measurements taken in the field (6.0 feet average, Section 2.7.2). As discussed, in a stream of this size, bankfull indicators were difficult to determine and in the field, the channel geometric shape was used to measure BFWs. This provided conservative estimates of the BFW.

In the cross sections upstream of the culvert backwater, average main channel velocities range from 1.4 feet per second (ft/s) during the 2-year event to 2.8 ft/s at the 500-year event. In the downstream reaches, average channel velocities range from 1.0 ft/s during the 2-year event to 2.0 ft/s during the 500-year event. Shear values in the upstream reach range from 1.0 pound per square foot (lb/SF) during the 2-year event to 3.9 lb/SF during the 500-year event. Shear values downstream range from 0.7 lb/SF at the 2-year event to 5.4 lb/SF during the 500-year event. The highest shear stress of 11.5 lb/SF occurs downstream of a natural drop in the downstream reach. Other than this location, no velocity or shear stresses hotspots are present in the upstream or downstream reach. At the culvert outlet, the velocity at the 500-year event is 2.7 ft/s with a shear stress of 7.9 lb/SF. Upstream the depths range from 0.5 foot during the 2-year event to 1.1 feet during the 500-year event. Depths in the downstream reach range from 0.6 foot at the 2-year event to 1.8 feet during the 500-year event. A plan view of the 100-year velocity magnitudes is depicted in Figure 60 and floodplain and main channel velocities are also summarized in Table 15.

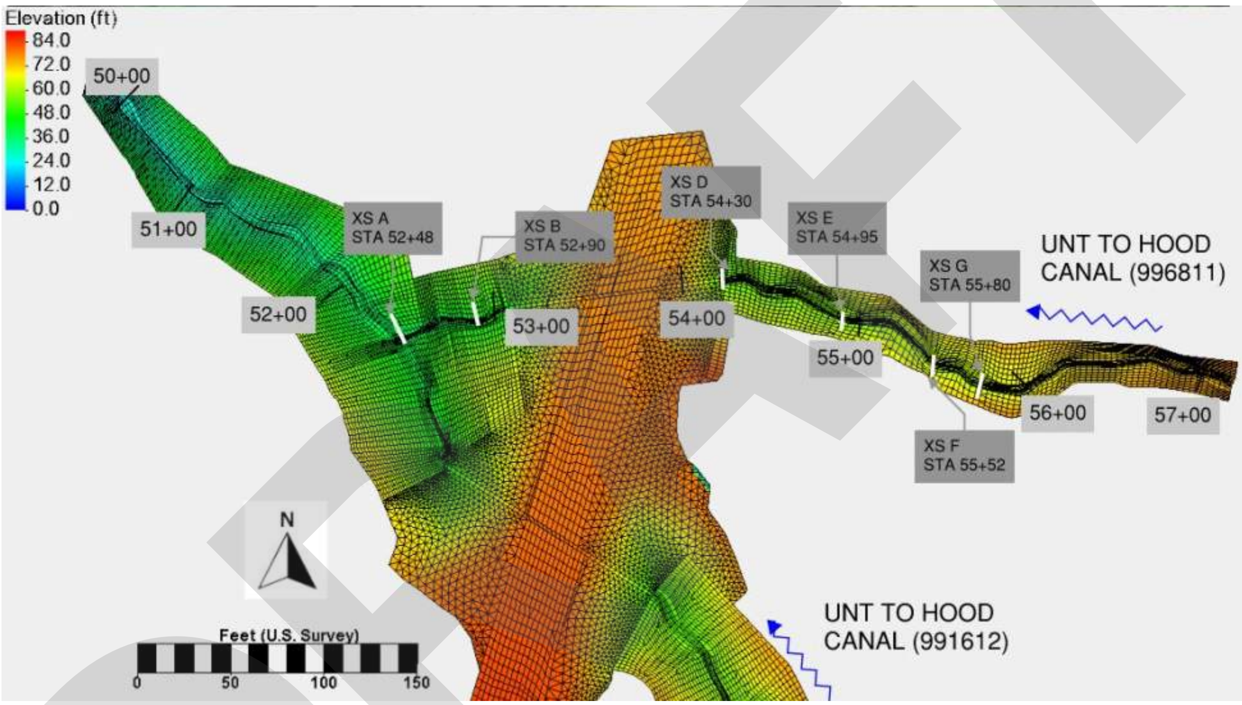

Figure 57: Locations of cross sections used for results reporting

Table 15: Average main channel hydraulic results for existing conditions

Hydraulic parameter	Cross section	2-year	100-year	500-year
Average WSE (ft)	DS 52+48 (A)	38.3	39.2	39.5
	DS 52+90 (B)	43.2	43.6	43.8
	Structure (C)	NA	NA	NA
	US 54+30 (D)	54.1	54.6	54.7
	US 54+95 (E)	56.9	57.4	57.5
	US 55+52 (F)	60.4	60.8	60.9
	US 55+80 (G)	61.9	62.3	62.4
Max depth (ft)	DS 52+48 (A)	0.6	1.5	1.8
	DS 52+90 (B)	0.7	1.1	1.2
	Structure (C)	NA	NA	NA
	US 54+30 (D)	0.5	0.9	1.1
	US 54+95 (E)	0.5	1.0	1.1
	US 55+52 (F)	0.5	0.9	1.1
	US 55+80 (G)	0.4	0.7	0.9
Average velocity (ft/s)	DS 52+48 (A)	1.0	1.2	1.1
	DS 52+90 (B)	1.2	2.0	2.1

Hydraulic parameter	Cross section	2-year	100-year	500-year
	Structure (C)	NA	NA	NA
	US 54+30 (D)	1.1	1.7	1.9
	US 54+95 (E)	1.4	2.1	2.3
	US 55+52 (F)	1.2	2.1	2.2
	US 55+80 (G)	1.5	2.5	2.8
Average shear (lb/SF)	DS 52+48 (A)	0.7	0.6	0.6
	DS 52+90 (B)	3.0	5.2	5.4
	Structure (C)	NA	NA	NA
	US 54+30 (D)	1.0	1.9	2.1
	US 54+95 (E)	1.1	2.0	2.4
	US 55+52 (F)	1.1	2.1	2.2
	US 55+80 (G)	1.5	3.5	3.9

Main channel extents were approximated by 2-year event water surface top widths.

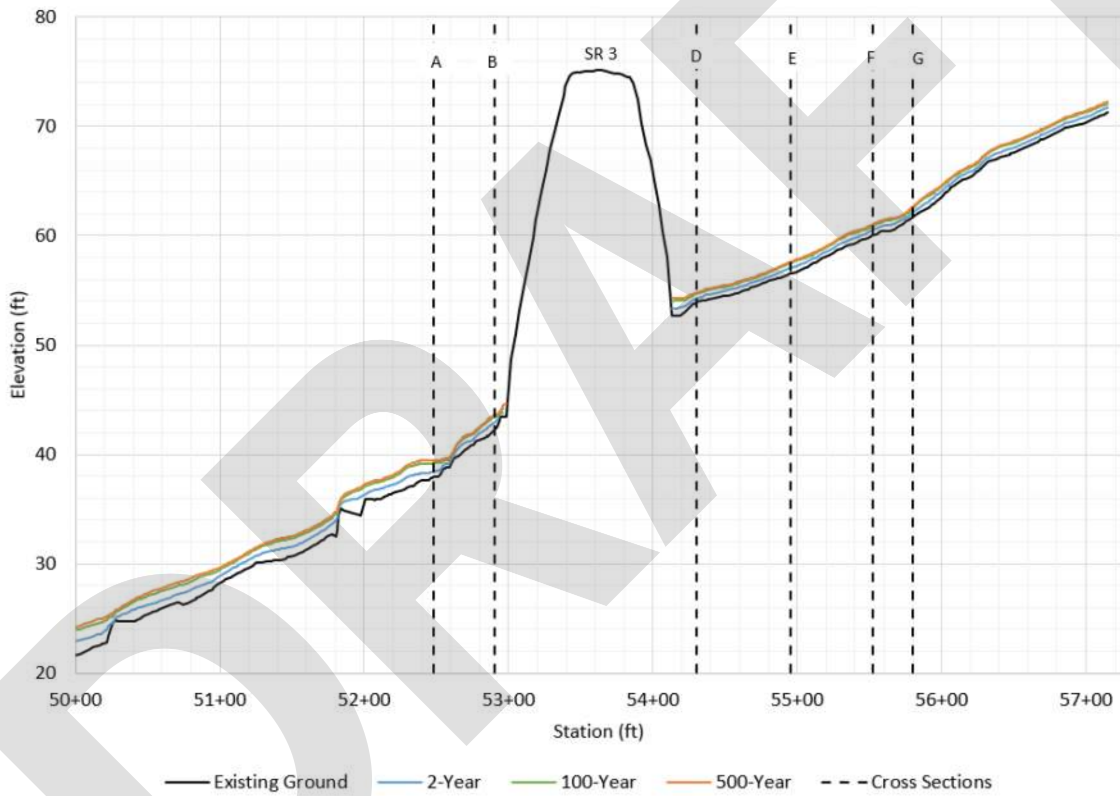

Figure 58: Existing-conditions water surface profiles

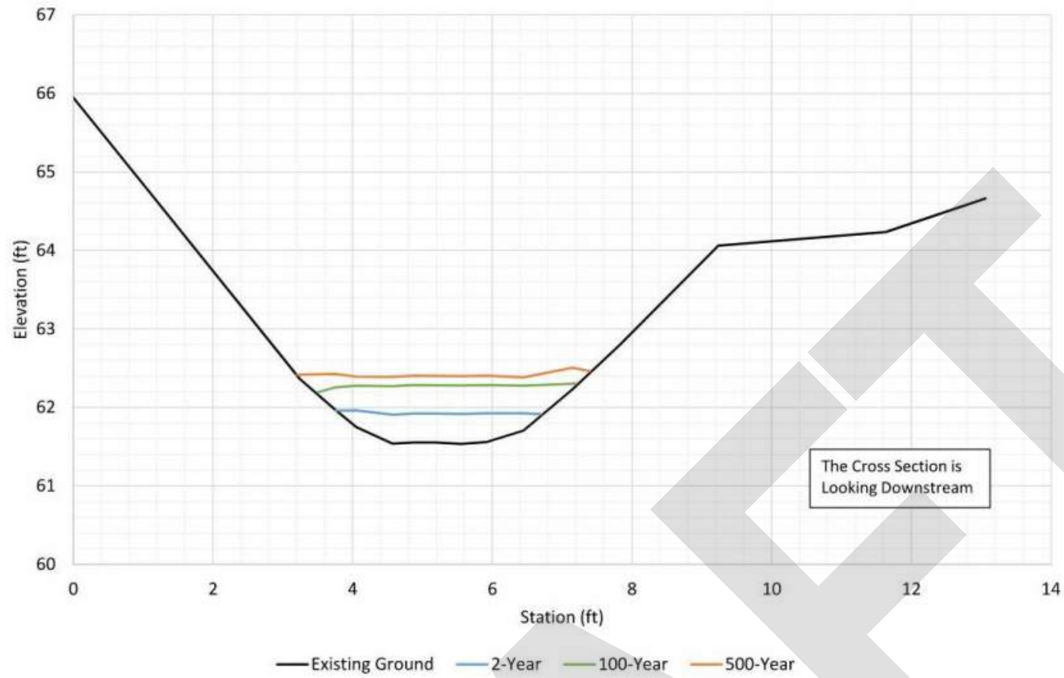

Figure 59: Typical upstream existing channel cross section (STA 55+80)

Figure 60: Existing-conditions 100-year velocity map with cross-section locations

Table 16: Existing-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities tributary scenario (ft/s)		
	LOB[a]	Main channel	ROB[a]
DS 52+48 (A)	0.4	1.2	0.9
DS 52+90 (B)	1.0	2.0	NA
Structure (C)	NA	NA	NA
US 54+30 (D)	0.2	1.7	0.5
US 54+95 (E)	NA	2.1	0.4
US 55+52 (F)	NA	2.1	0.5
US 55+80 (G)	0.7	2.5	NA

Right overbank (ROB)/left overbank (LOB) locations were approximated by 2-year event water surface top widths.

5.3 Natural Conditions

A natural-conditions model was not required as the system is confined.

5.4 Proposed Conditions: 15-foot Minimum Hydraulic Width

The hydraulic width is defined as the width perpendicular to the creek beneath the proposed structure that is necessary to convey the design flow and allow for natural geomorphic processes. The hydraulic modeling assumes vertical walls at the edge of the minimum hydraulic width unless otherwise specified. See Section 4.2 for a description of how the minimum hydraulic width was determined.

Comparing the existing and proposed conditions, the greatest change occurs at the culvert inlet. Backwater is eliminated and the depth drops from 1.1 feet to 0.9 foot from existing to proposed conditions. The WSEs at STA 4+94 for the 100-year and 500-year event decrease by 0.1 foot from existing to proposed. Proposed-conditions main channel hydraulic results are summarized for the upstream and downstream cross sections in Table 17. When comparing velocities and shear stresses throughout the reach, the velocities vary the most at the 500-year event: as much as 1.9 ft/s from upstream to downstream and the shear stresses vary as much as 3.5 lb/SF. Refer to Figure 61 for the alignment used for reporting proposed results and cross-section locations and stations. The longitudinal stationing varies in existing versus proposed conditions, but the location of each cross section, denoted by letters, is the same between existing and proposed conditions. See Appendix H for detailed results for velocities, WSEs, depths, and shear values for each flow event. A longitudinal profile is shown in Figure 62, and a typical section through the structure is depicted in Figure 63. The WSEs shown within the cross section do not reflect the BFW measurements taken in the field (6.0 feet average, Section 2.7.2). As discussed, in a stream of this size, bankfull indicators were difficult to determine and in the field, the channel geometric shape was used to measure BFWs. This provided conservative estimates of the BFW. Proposed-conditions 100-year velocities are depicted in Figure 64. Average floodplain and main channel velocities are summarized in Table 18.

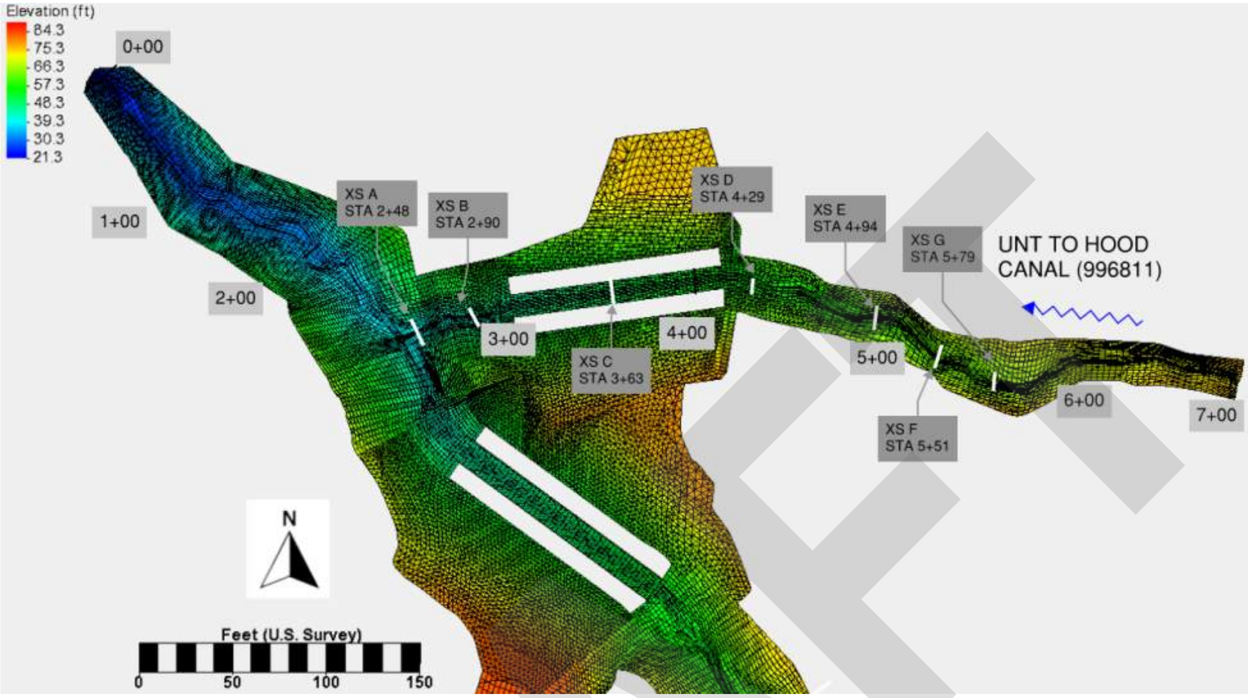

Figure 61: Locations of cross sections on proposed alignment used for results reporting

Table 17: Average main channel hydraulic results for proposed conditions

Hydraulic parameter	Cross section	2-year	100-year	Projected 2080 100-year	500-year
Average WSE (ft)	DS 2+48 (A)	38.3	39.2	39.6	39.5
	DS 2+90 (B)	43.1	43.4	43.7	43.6
	Structure STA 3+63 (C)	48.6	48.9	49.1	49.0
	US 4+29 (D)	53.9	54.2	54.4	54.3
	US 4+94 (E)	56.9	57.4	57.6	57.5
	US 5+51 (F)	60.4	60.8	61.0	60.9
	US 5+79 (G)	61.9	62.3	62.5	62.4
Max depth (ft)	DS 2+48 (A)	0.6	1.5	1.9	1.8
	DS 2+90 (B)	0.4	0.8	1.0	0.9
	Structure STA 3+63 (C)	0.5	0.8	1.0	0.9
	US 4+29 (D)	0.5	0.8	1.0	0.9
	US 4+94 (E)	0.5	1.0	1.2	1.1
	US 5+51 (F)	0.5	0.9	1.1	1.1
	US 5+79 (G)	0.4	0.7	0.9	0.9
Average velocity (ft/s)	DS 2+48 (A)	1.0	1.2	1.2	1.1
	DS 2+90 (B)	1.5	2.7	3.0	2.9
	Structure STA 3+63 (C)	1.5	2.7	3.0	2.9
	US 4+29 (D)	1.6	2.7	3.1	3.0
	US 4+94 (E)	1.4	2.1	2.4	2.3
	US 5+51 (F)	1.2	2.1	2.3	2.2
	US 5+79 (G)	1.5	2.5	2.9	2.8
Average shear (lb/SF)	DS 2+48 (A)	0.7	0.6	0.6	0.6
	DS 2+90 (B)	1.7	3.3	3.6	3.5
	Structure STA 3+63 (C)	1.6	2.9	3.5	3.3
	US 4+29 (D)	1.6	2.9	3.5	3.3
	US 4+94 (E)	1.1	2.0	2.5	2.4
	US 5+51 (F)	1.1	2.1	2.3	2.2
	US 5+79 (G)	1.5	3.5	4.1	3.9

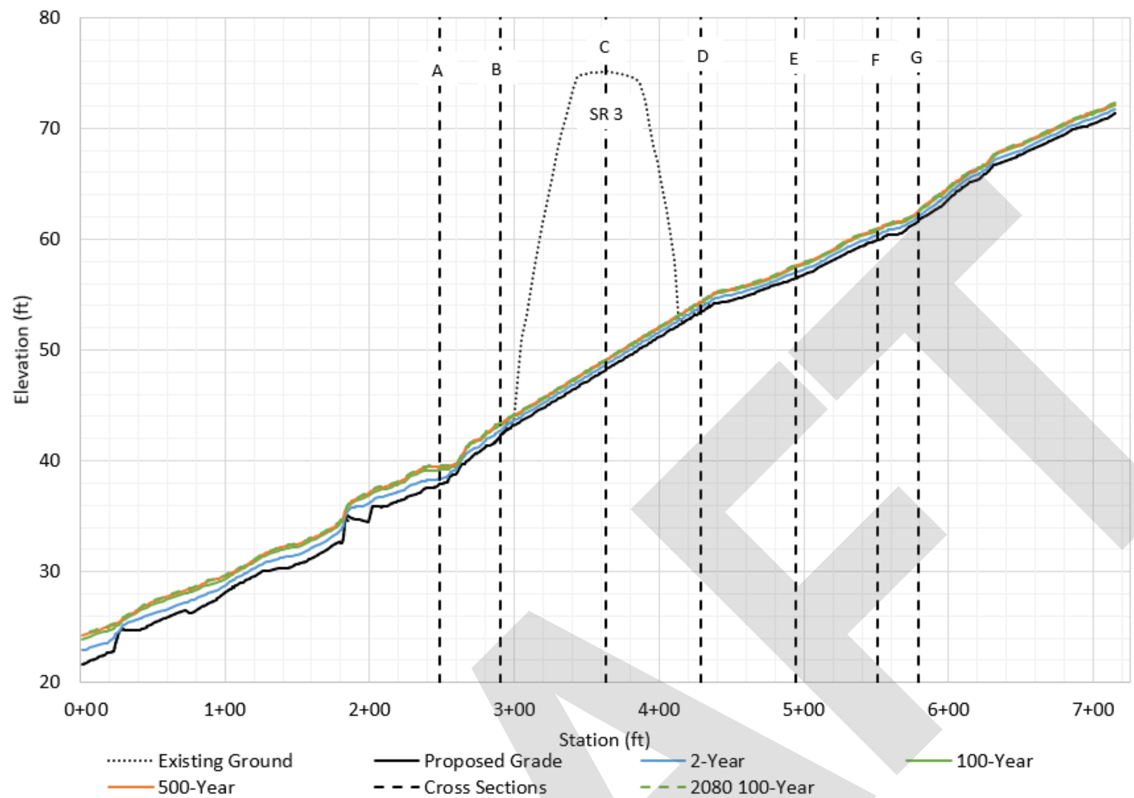

Figure 62: Proposed-conditions water surface profiles

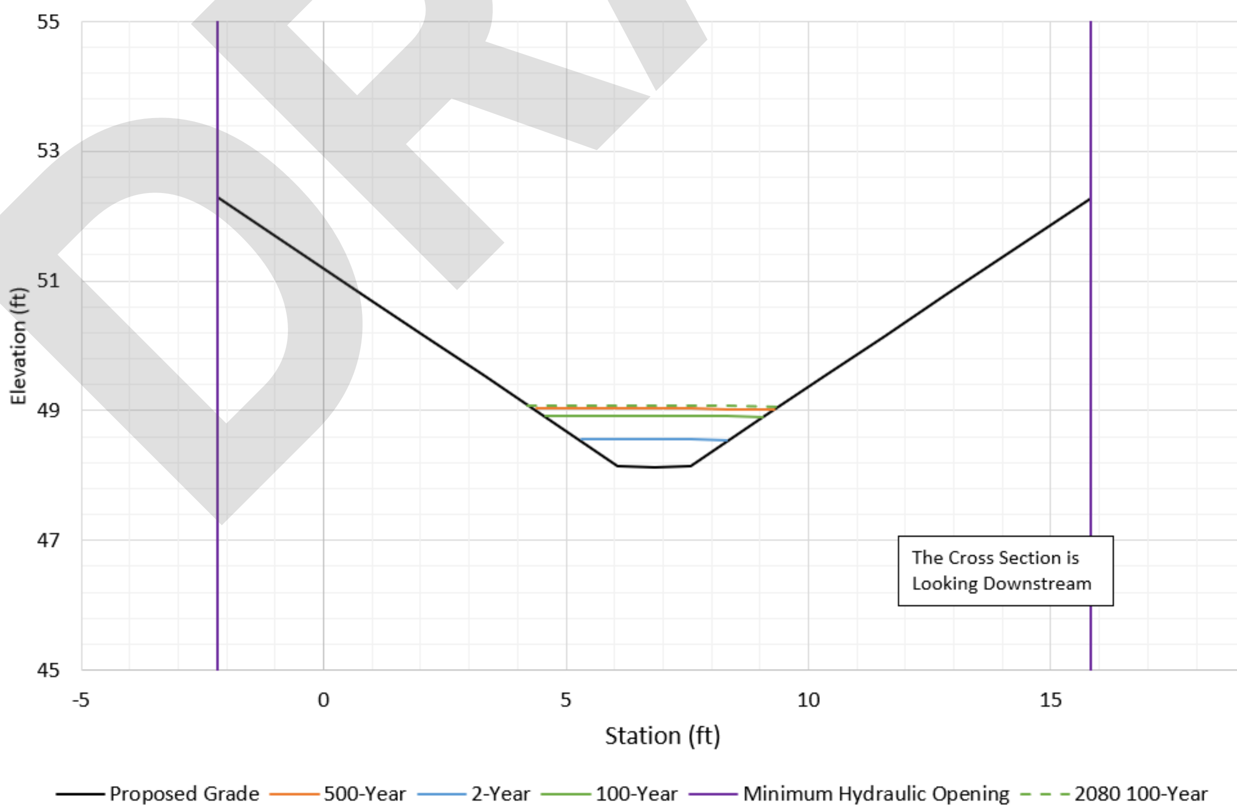

Figure 63: Typical section through proposed structure (STA 3+63)

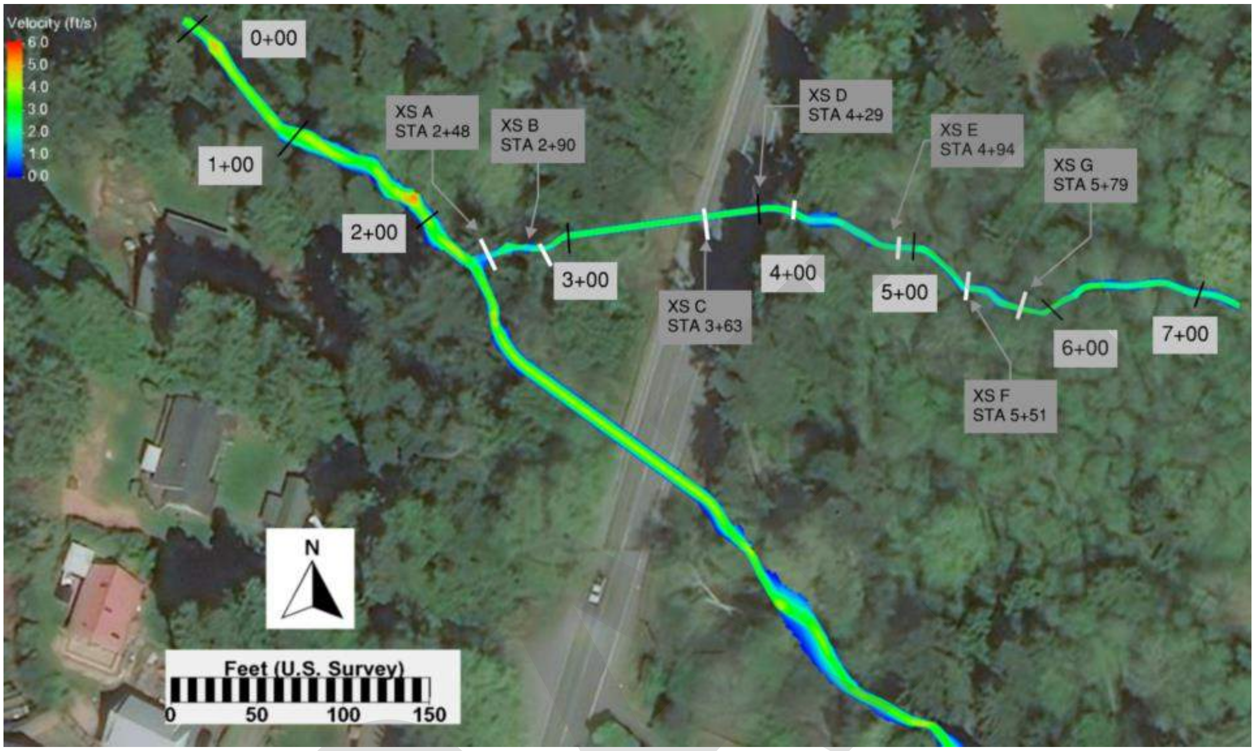

Figure 64: Proposed-conditions 100-year velocity map

Table 18: Proposed-conditions average channel and floodplains velocities

Cross-section location	Q100 average velocities (ft/s)			2080 Q100 average velocity (ft/s)		
	LOB[a]	Main channel	ROB[a]	LOB[a]	Main channel	ROB[a]
DS 2+48 (A)	0.4	1.2	0.9	0.5	1.2	0.3
DS 2+90 (B)	1.2	2.7	NA	1.9	3.0	0.9
Structure STA 3+63 (C)	1.0	2.7	1.2	1.7	3.0	1.9
US 4+29 (D)	1.3	2.7	1.4	2.0	3.1	2.0
US 4+94 (E)	NA	2.1	0.4	NA	2.4	0.6
US 5+51 (F)	NA	2.1	0.5	0.4	2.3	0.9
US 5+79 (G)	0.7	2.5	NA	1.3	2.9	0.6

Right overbank (ROB)/left overbank (LOB) locations were approximated by 2-year event water surface top widths.

6 Floodplain Evaluation

This project is not within a FEMA special flood hazard area (SFHA) but outlets into Hood Canal, which has a FEMA zone AE SFHA with a base elevation of 14 feet 450 feet downstream of the project culvert outlet (FEMA 2020). The project is within Zone X, which is described as an area of minimal flooding; see Appendix A for the FIRMette (ID 53035C0105F). The existing-project and expected proposed-project conditions were evaluated to determine whether the project would cause a change in flood risk.

6.1 Water Surface Elevations

Installation of the proposed structure would eliminate the backwater impacts immediately upstream of the existing culvert, resulting in a reduction in WSE upstream. The WSE is reduced by as much as 0.6 foot at the inlet of the existing culvert at the 100-year event as shown in Figure 65. Figure 66 depicts the extent of backwater that is eliminated. Upstream of the culvert, the water surface has dropped because the backwater was eliminated. Downstream, within grading extents the channel has expanded so there is a localized area of new water surface extents immediately downstream of the culvert. Downstream and upstream of the project site, there is no WSE change.

A flood risk assessment will be developed during later stages of the design. The risk to infrastructure downstream of the crossing is low as the model shows that no changes occur downstream of the immediate vicinity of the culvert outlet.

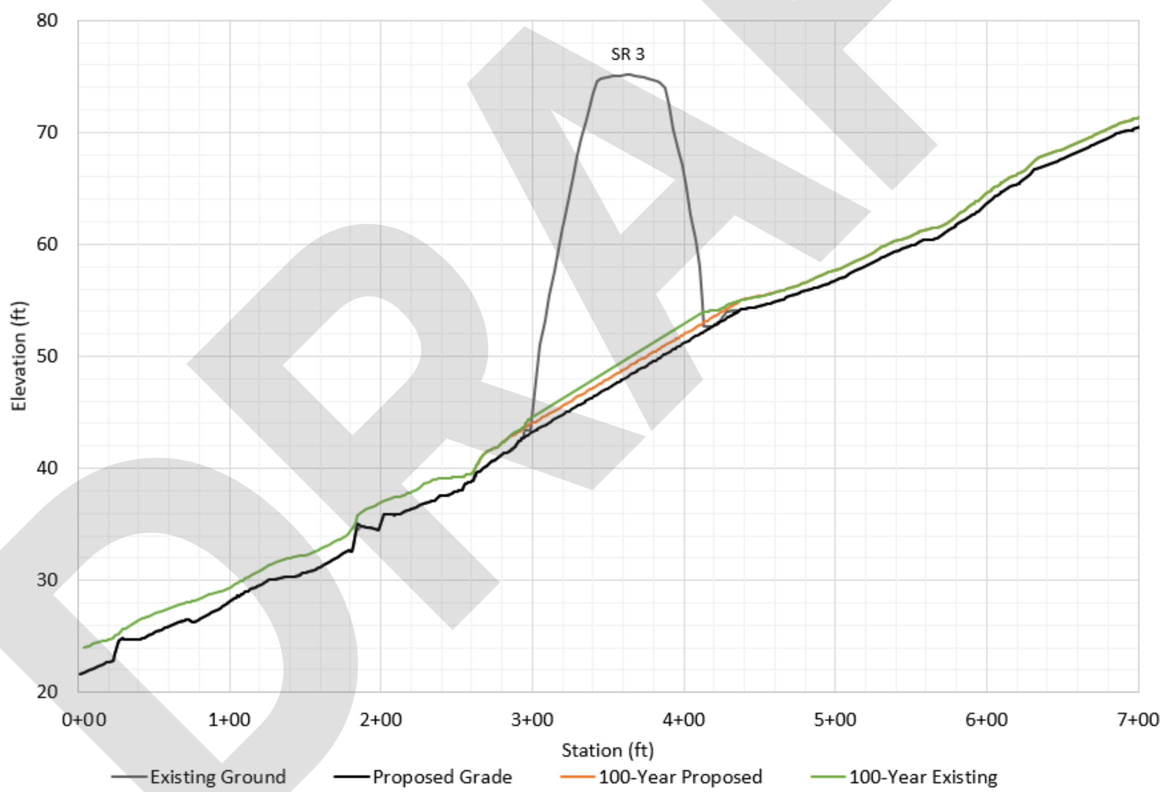

Figure 65: Existing- and proposed-conditions 100-year water surface profile comparison along proposed alignment

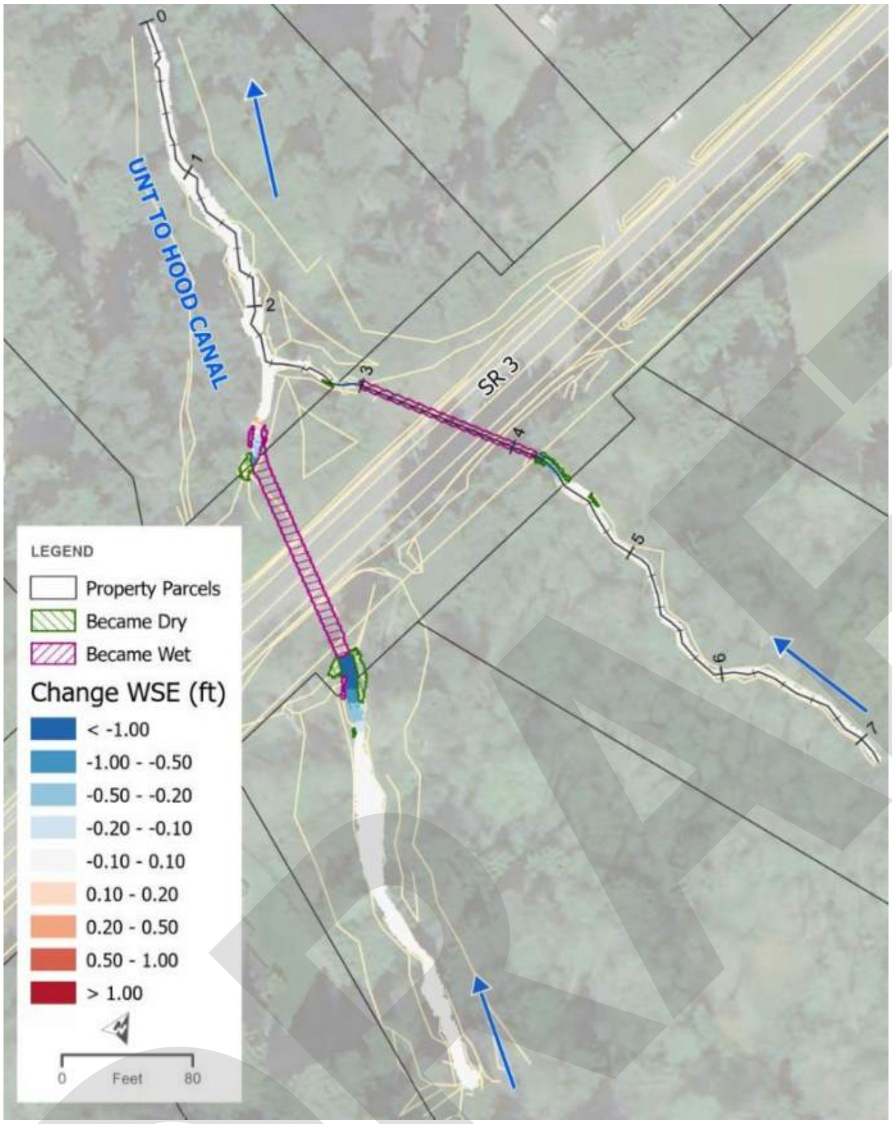

Figure 66: 100-year WSE change from existing to proposed conditions

7 Preliminary Scour Analysis

For this preliminary phase of the project, the risk for lateral migration, potential for long-term degradation, and evaluation of preliminary total scour is based on available data, including but not limited to site conditions, modeling results, and preliminary geotechnical borings. This evaluation is to be considered preliminary and is not to be taken as a final recommendation.

Using the results of the hydraulic analysis (Section 5), based on the recommended MHO of 15 feet, and considering the potential for lateral channel migration, preliminary scour calculations for the scour design flood and scour check flood were performed following the procedures outlined in *Evaluating Scour at Bridges,* Hydrologic Engineering Center (HEC)-18 (Arneson et al. 2012). The 2-year (1.8 cfs), 100-year (6.3 cfs), 500-year (8.2 cfs), and 2080 100-year (9.1 cfs) flow events were evaluated to determine the deepest depth of scour for each scour component. Additional flows were not analyzed due to the relatively low peak flow values and range of flows analyzed were only separated by 7 cfs between the 2-year and 1080 100-year event. The 2080 100-year flow event was used as both the scour design flood and scour check flood event. Scour components considered in the analysis include:

- Long-term degradation
- Contraction scour
- Local scour

In addition to the three scour components listed above, the potential for lateral migration was assessed to evaluate total scour at the proposed highway infrastructure. These various scour components are discussed in the following sections.

7.1 Lateral Migration

Historical and existing conditions were evaluated with historical aerial photography, site observations and modeled flows through the existing topography to assess lateral migration. These existing conditions are compared to proposed conditions. Past aerial photography provides little information regarding channel migration as explained in Section 2.7.5. Currently, the channel is confined within a valley with an average valley width of approximately 20 feet based on field measurements. The structure has a 15-foot MHO, and lateral migration may occur within this opening. The structure has been sized to allow lateral migration to the magnitude of one BFW to either side of the channel.

A draft geotechnical boring was provided near SR 3 MP 59.52, WDFW site ID 991612, which is the neighboring crossing to the south. Due to lack of geotechnical data at this crossing, data from MP 59.52 was utilized for this phase of design. The boring shows that at depths of 20 to 35 feet, which are the approximate depth of the proposed channel thalweg relative to the boring hole, material is primarily poorly graded sand with some silts and gravels. At a depth of approximately 40 feet, the material transitions to silty sand and is noted to be very dense. This preliminary boring investigation shows that poorly graded soils near the surface of the channel may be susceptible to lateral migration and liquefaction; in the case that the channel degrades, and deeper soils are exposed, it is possible that the very dense nature of the silty sands below may mitigate further degradation. Competent bedrock was not located in the draft boring (WSDOT 2022c).

The risk will be assessed in more detail once the Geotechnical Memorandum is received; it is currently in progress.

Based on site observations, the channel shows signs of degradation and aggradation. Gravel and sand deposits were observed upstream of small woody debris acting as forced step pools, indicating signs of aggradation. Expanding beyond the focus of the channel within the banks, site observations indicate that the channel has migrated within the valley, leaving behind benches and terraces that no longer are activated at the highest flow events. The channel, terraces, and valley dynamics have shifted and evolved over time, indicating that the channel has a Stage IV classification (Schumm et al. 1984). This stabilizing channel stage of the evolution model indicates that the channel has already undergone an incision, widening, and bank failure stage. At Stage IV, the channel migrates laterally within its floodplain at channel-forming flow events; changes in flow path may occur as the result of bank erosion, sediment deposition, and recruitment of woody material.

Proposed conditions will match the existing-conditions sediment gradation and stability (see Section 4.3.1). The existing channel is well defined and steep, and the planform is mostly straight with some sinuosity. It has a step-pool morphology formed by cobbles and LWM, with riffle sections between the step pools. The observed step pools are deformable, and the proposed step pools will be formed by cobbles at a gradation with a stable D_{84} at all events (see Section 4.3.1). Based on site observations of aggradation and degradation, the channel is not actively incising within the topographic survey (see Sections 2.7.4 and 7.2). The proposed bed material will mimic existing conditions and the channel is locally expected to remain balanced in terms of aggradation and degradation. The long-term aggradation and degradation equilibrium slope estimates approximately 4 feet of degradation (Section 7.2). This will affect lateral migration if the channel downcuts, but this estimation must be confirmed with the Geotechnical Memorandum.

Shear and velocity changes were assessed from modeled existing versus proposed conditions. The velocity and shear increase immediately upstream of the culvert inlet from proposed to existing conditions because of eliminated backwater effects by a maximum of about 1.1 ft/s and 1.2 lb/SF. The velocity and shear through the structure are equal to the conditions upstream of the structure under proposed conditions. The change in velocities and shear is minimal; as a result, change in bank erosion and stream scour based on hydraulic model results is not expected.

To summarize, stream migration is anticipated to be low based on channel observations and modeling results; however, a draft geotechnical boring shows that soils within the area could easily be susceptible to lateral migration. The lateral migration risk to the structure is considered to be not low, but this will need to be confirmed with information from the forthcoming Geotechnical Memorandum and associated detailed geotechnical data. Refer to Section 8 for a discussion on potential scour countermeasures.

7.2 Long-term Degradation of the Channel Bed

Signs of deposition were observed in the surveyed reach. Localized deposition occurs throughout the channel upstream of step-pool features formed by cobbles and small woody debris. Both localized erosion and deposition are observed, indicating that the surveyed reach is not actively incising or aggrading. According to the initial Geotechnical Scoping Package prepared for the nearby crossing SR 3 MP 59.52 (991612), the glacial till observed downstream of both crossings 59.52 and 59.55 is a mixture of clay, sand, gravel, and cobbles that has been overconsolidated and cemented. The glacial till is classified as Low Erodibility, is relatively scour-resistant, and may act as a base level control for long-term degradation. This conclusion is contingent upon the Geotechnical Memorandum. The Geotechnical Memorandum is underway and has not yet been completed but will be used to help assess long-term aggradation and degradation. See Section 2.7.4 for more discussion of localized aggradation and degradation.

To estimate the local degradation or aggradation an equilibrium slope was projected from a downstream base control point. This base control point elevation is based on an estimation of where the channel ends and Hood Canal begins and is assumed to be a hard point in the vertical profile of the stream. This base control point elevation of 8 feet was based on site observations (Figure 27 above) and LiDAR, which indicate where the channel no longer maintains its cross-sectional shape and the substrate composition changes. It is a conservative estimate, considering that the glacial till noted above may be an appropriate base level control point as well. The mean higher-high water (MHHW) for the Port Townsend tidal gage occurs at 7.4 feet, which aligns well with the base control point of 8 feet. These values were pulled from the National Oceanic and Atmospheric Administration's (NOAA's) tide gage 9444900 in Port Townsend, Washington, and converted to NAVD88 using NOAA's Online Vertical Datum Transformation (Vdatum) tool (NOAA 2022). To provide a range of anticipated degradation, a second base control point was also located on the profile at the downstream existing elevation of approximately 14 feet, and a third base control point was estimated at the location that glacial till was viewed in the field.

Based on the FEMA floodplain map of UNT to Hood Canal, the tidal base flood elevation is 14 feet, well outside the proposed grading of the crossing. The equilibrium slope is projected from three different assumed base control points upstream at a 7.4 percent slope, which matches the existing slope based on the long profile. From this projection, degradation was estimated to be 0 to 4.3 feet, as depicted in Figure 67. It is possible no degradation will occur, but up to 4.3 feet could occur as a conservative estimate if a headcut propagated from the most downstream assumed base level control point. The diversion dam, which has the potential to cause a headcut to propagate upstream if it were removed, has a 27-inch vertical surface drop, which is within this range of 0 to 4.3 feet. Therefore, it would have a smaller effect than the more conservative large-scale channel adjustment. The glacial till in the downstream reach may make the channel more resistant to vertical bed adjustments, and the lack of vertical grade breaks indicates that a headcut or large channel regrade is not likely. From the glacial till base control point projection, degradation was estimated to be 0 to 1.9 feet, also depicted in Figure 67. An additional scour analysis, which will be completed during the FHD, is needed to quantify and verify the amount of scour once additional geotechnical data are available. The draft geotechnical boring indicates there was no bedrock or non-erodible soils in the one boring hole conducted May 16 and 17, 2022, though the glacial till was identified as Low Erodibility. More geotechnical analysis needs to be done to verify the appropriate base control point.

Additional equilibrium slopes were calculated using the Shields' and Meyer-Peter Muller equations; however, each of these resulted in equilibrium slopes of less than 1 percent and were deemed to not be applicable at this site (Lagasse et. al 2012b).

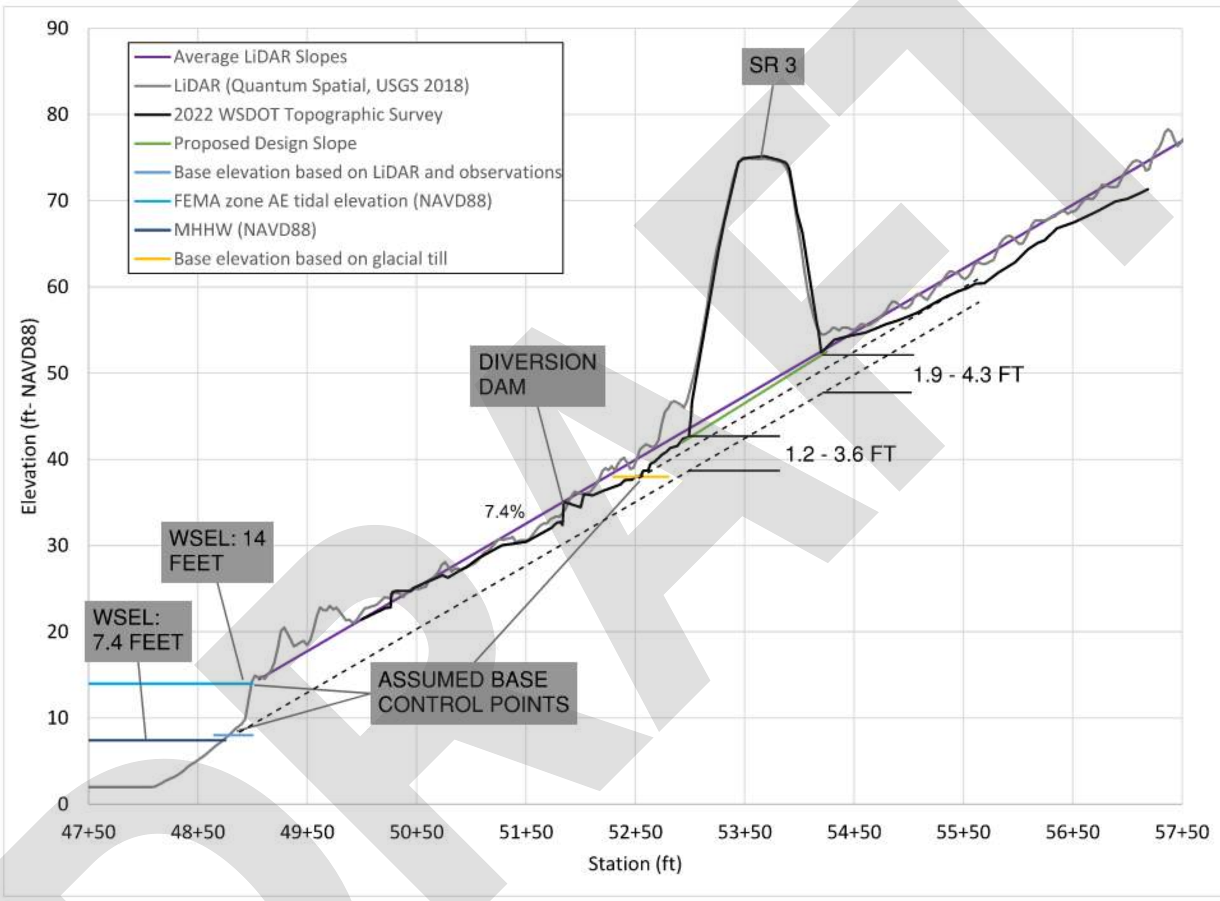

Figure 67: Potential long-term degradation at the upstream and downstream face of the proposed structure

7.3 Contraction Scour

Estimates of contraction scour were calculated following the methodology outlined in Chapter 6 of HEC-18 (Arneson et al. 2012) for non-cohesive materials, by using the hydraulic toolbox output in SMS (Aquaveo 2021; Appendix A).

The analysis indicates that the clear-water contraction scour condition will exist at the scour design flood and scour check flood events because flow velocity upstream of the bridge opening is less than the critical velocity. Therefore, the clear-water condition was used to determine contraction scour at this site. Clear-water scour equations estimate 0 feet of scour for the MHO of 15 feet under the scour design and check flood events.

At the PHD phase step pools have not been modeled and, as a result, contraction scour does not consider the step-pool habitat features. As design progresses, contraction scour will need to be revisited to determine the effect of step pools on scour.

7.4 Local Scour

The following sections describe the scour methodology and results of the local scour components. Detailed calculations for local scour are provided in Appendix K.

7.4.1 Pier Scour

The crossing will not have piers and therefore pier scour was not calculated.

7.4.2 Abutment Scour

Abutment scour was estimated using the National Cooperative Highway Research Program (NCHRP) 24-20 approach, as described in Chapter 8 of HEC-18 (Arneson et al. 2012) for the scour design and scour check flood events. Though it is not anticipated that abutments will protrude into the flow path in the scour design or check flood events, abutment scour was quantified at this crossing as condition A due to the potential for lateral migration (Section 7.1). The abutment scour calculated using the NCHRP methodology represents total scour at the abutment and should not be added to contraction scour because it already includes the contraction component. Abutment scour was calculated assuming a vertical wall and quantified as 0.4 foot at the crossing during the scour design and check flood events.

7.4.3 Bend Scour

Bend scour was calculated following the methodology outlined in HEC-23 (Lagasse et al. 2012a). Depth of bend scour was estimated using Maynord’s method. The analysis indicates that the depth of bend scour ranges from 0.2 foot to 0.7 foot through the scour design flood and scour check flood; this was applied to the total scour estimate to account for potential lateral migration that may occur within the structure.

7.5 Total Scour

Calculated total depths of scour for the scour design flood and scour check flood as shown in the plans dated August 2022 at the proposed UNT to Hood Canal at MP 59.55 structure, as designed in this PHD Report, are provided in Table 19. HQ Hydraulics recommends that each infrastructure component be designed to account for the depths of scour provided in Table 19. The total scour is to be applied to the thalweg elevation. Scour depths are estimated at the upstream face in Table 19. At the time of the writing of this PHD, no coordination has occurred with the Project Office, HQ Geotechnical, or HQ Bridge regarding scour; this will occur at future stages of design.

Table 19: Scour analysis summary

Calculated scour components and total scour for SR 3 MP 59.55 UNT to Hood Canal		
	Scour design flood	Scour check flood
Long-term degradation (ft)*	0.0 - 4.3	0.0 - 4.3
Contraction scour (ft)	0.0	0.0
Local scour (ft)		
Pier scour (ft)	0.0	0.0
Abutment scour (ft)	0.4	0.4
Bend scour (ft)	0.7	0.7
Total depth of scour (ft)	5.4	5.4

* Upstream Face

8 Scour Countermeasures

At this stage in design, from a hydraulic standpoint scour countermeasures are not required at this crossing. This assumption is based on results of the scour analysis (Section 7) and field observations (Section 2.7.4). Contraction scour is estimated as 0.0 feet. Local scour, including abutment and bend scour, is estimated as 1.1 feet. Degradation at the site is expected on a long-term basis on the order of 0 to 4.3 feet based on visual inspection of the equilibrium slope. Total scour is anticipated to be a maximum of 5.4 feet. Additionally, no LWM have been proposed inside the crossing structure and accumulation of LWM at the inlet of the structure is not anticipated. Further coordination is required to make a final determination of the inclusion of scour countermeasures at the site.

At this preliminary design phase, step pools have not been explicitly modeled within the hydraulic model and any potential effect they may have on scour within the structure has not been included within this PHD Report. Once the structure type has been determined and the step-pool design has been finalized, scour and the need for scour countermeasures will be reassessed and discussed with the project office. Plan and section view designs will be provided following future coordination. If scour countermeasures are determined to be required in future stages of design, they will not encroach within the MHO.

9 Summary

Table 20 presents a summary of the results of this PHD Report.

Table 20: Report summary

Stream crossing category	Element	Value	Report location
Habitat gain	Total length	2,100 LF	2.1 Site Description
Bankfull width	Reference reach found?	Yes	2.7.1 Reference Reach Selection
	Design BFW	6.0 ft	2.7.2 Channel Geometry
	Concurrence BFW	6.0 ft	2.7.2 Channel Geometry
Floodplain utilization ratio (FUR)	Flood-prone width	4.6 ft	2.7.2.1 Floodplain Utilization Ratio
	Average FUR	1.3	2.7.2.1 Floodplain Utilization Ratio
Channel morphology	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.3.2 Channel Complexity
Hydrology/design flows	100 yr flow	6.3 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr flow	9.1 cfs	3 Hydrology and Peak Flow Estimates
	2080 100 yr used for design	N	3 Hydrology and Peak Flow Estimates
	Dry channel in summer	NA	3 Hydrology and Peak Flow Estimates
Channel geometry	Existing	See link	2.7.2 Channel Geometry
	Proposed	See link	4.1.1 Channel Planform and Shape
Channel slope/gradient	Existing culvert	7.8%	2.6.2 Existing Conditions
	Reference reach	6.8%	2.7.1 Reference Reach Selection
	Proposed	8.0%	4.1.3 Channel Gradient
Hydraulic width	Existing	2 ft	2.6.2 Existing Conditions
	Proposed	15 ft	4.2.2 Hydraulic Width
	Added for climate resilience	No	4.2.2 Hydraulic Width
Vertical clearance	Required freeboard	1.0 ft	4.2.3 Vertical Clearance
	Required freeboard applied to 100 yr or 2080 100 yr	2080 100 yr	4.2.3 Vertical Clearance
	Maintenance clearance	Required 6 ft	4.2.3 Vertical Clearance
	Low chord elevation	See link	4.2.3 Vertical Clearance
Crossing length	Existing	120 ft	2.6.2 Existing Conditions
	Proposed	97 ft	4.2.4 Hydraulic Length
Structure type	Recommendation	No	4.2.6 Structure Type
	Type		4.2.6 Structure Type
Substrate	Existing	See link	2.7.3 Sediment
	Proposed	See link	4.3.1 Bed Material
	Coarser than existing?	Yes	4.3.1 Bed Material
Channel complexity	LWM for bank stability	Yes	4.3.2 Channel Complexity
	LWM for habitat	Yes	4.3.2 Channel Complexity
	LWM within structure	No	4.3.2 Channel Complexity
	Meander bars	No	4.3.2 Channel Complexity
	Boulder clusters	No	4.3.2 Channel Complexity

Stream crossing category	Element	Value	Report location
	Coarse bands/crest steps	3 - 5	4.3.2 Channel Complexity
	Mobile wood	Yes	4.3.2 Channel Complexity
Floodplain continuity	FEMA mapped floodplain	No	6 Floodplain Evaluation
	Lateral migration	Yes	2.7.5 Channel Migration
	Floodplain changes?	No	6 Floodplain Evaluation
Scour	Analysis	See link	7 Preliminary Scour Analysis
	Scour countermeasures	Determined at FHD	8 Scour Countermeasures
Channel degradation	Potential?	0 to 5.4 feet	7.5 Total Scour
Channel degradation	Allowed?	Yes	7.2 Long-term Degradation of the Channel Bed

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Appendices

Appendix A: FEMA Floodplain Map

Appendix B: Hydraulic Field Report Form

Appendix C: Streambed Material Sizing Calculations

Appendix D: Stream Plan Sheets, Profile, Details

Appendix E: Manning’s Calculations

Appendix F: Large Woody Material Calculations

Appendix G: Future Projections for Climate-Adapted Culvert Design

Appendix H: SRH-2D Model Results

Appendix I: SRH-2D Model Stability and Continuity

Appendix J: Reach Assessment (NA)

Appendix K: Scour Calculations

Appendix L: Floodplain Analysis (FHD ONLY)

Appendix M: Scour Countermeasure Calculations (FHD ONLY)

Appendix A: FEMA Floodplain Map

National Flood Hazard Layer FIRMette

FEMA

122°37'12"W 47°50'55"N

122°36'35"W 47°50'31"N

Feet

0 250 500 1,000 1,500 2,000

1:6,000

Basemap: USGS National Map: Orthoimagery: Data refreshed October, 2020

Legend

SEE FIS REPORT FOR DETAILED LEGEND AND INDEX MAP FOR FIRM PANEL LAYOUT

SPECIAL FLOOD HAZARD AREAS
- Without Base Flood Elevation (BFE) *Zone A, V, A99*
- With BFE or Depth *Zone AE, AO, AH, VE, AR*
- Regulatory Floodway

OTHER AREAS OF FLOOD HAZARD
- 0.2% Annual Chance Flood Hazard, Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile *Zone X*
- Future Conditions 1% Annual Chance Flood Hazard *Zone X*
- Area with Reduced Flood Risk due to Levee. See Notes. *Zone X*
- Area with Flood Risk due to Levee *Zone D*

OTHER AREAS
- NO SCREEN Area of Minimal Flood Hazard *Zone X*
- Effective LOMRs
- Area of Undetermined Flood Hazard *Zone D*

GENERAL STRUCTURES
- Channel, Culvert, or Storm Sewer
- Levee, Dike, or Floodwall

OTHER FEATURES
- B 20.2 / 17.5 Cross Sections with 1% Annual Chance Water Surface Elevation
- 8 Coastal Transect
- 513 Base Flood Elevation Line (BFE)
- Limit of Study
- Jurisdiction Boundary
- Coastal Transect Baseline
- Profile Baseline
- Hydrographic Feature

MAP PANELS
- Digital Data Available
- No Digital Data Available
- Unmapped

N

The pin displayed on the map is an approximate point selected by the user and does not represent an authoritative property location.

This map complies with FEMA's standards for the use of digital flood maps if it is not void as described below. The basemap shown complies with FEMA's basemap accuracy standards

The flood hazard information is derived directly from the authoritative NFHL web services provided by FEMA. This map was exported on 12/28/2021 at 6:50 PM and does not reflect changes or amendments subsequent to this date and time. The NFHL and effective information may change or become superseded by new data over time.

This map image is void if the one or more of the following map elements do not appear: basemap imagery, flood zone labels, legend, scale bar, map creation date, community identifiers, FIRM panel number, and FIRM effective date. Map images for unmapped and unmodernized areas cannot be used for regulatory purposes.

Appendix B: Hydraulic Field Report Form

WSDOT Hydraulics Section

Site Visit 2 Field Report

Project Name: WSDOT Olympic Region GEC- Task Order AC		**Project Number:** Y12554 Task AC / WX305003
Project Office: Olympic Region PEO		**Date:** 3/15/22
Stream Name: UNT		**Time of Arrival:** 1:30 PM
		Time of Departure: 4:30 PM
WDFW ID Number: 996811	**Tributary to:** Hood Canal	**Weather:** Partly Cloudy, 55° F
State Route/MP: SR 3/MP 59.55	**Township/Range/Section/ ¼ Section:** T27N/R1E/S12/NW	**Prepared By:** Kristin LaForge
County: Kitsap	**Purpose of Site Visit:** Site Reconnaissance	**WRIA:** 15

Meeting Location:
UNT to Hood Canal, SR 3, MP 59.55

Attendance List:

Name	Organization	Role
Ian Welch	HDR	Biologist
Rachel Ainslie	HDR	Water Resources EIT
Kristin LaForge	HDR	Water Resources EIT

Observations:

Describe measurements, locations, known history, summarize on site discussion.

HDR conducted an independent site visit on March 15, 2022 to measure bankfull widths (BFWs), collect pebble count data, and locate a reference reach. HDR walked the stream approximately 300 feet upstream and approximately 60 feet downstream of the existing 2-foot RCP (reinforced concrete pipe) circular culvert crossing. Detailed site reconnaissance notes were taken 300 feet upstream to 60 feet downstream until the confluence with UNT to Hood Canal. See the field report for the SR 3 MP 59.52 crossing for measurements and observations downstream of the confluence. HDR took six BFW measurements upstream of the crossing and none downstream of the crossing. See Figure 1 for measurement locations.

A second site visit with HDR, WSDOT, WDFW and the tribes has not yet been conducted to gain concurrence on BFWs and other design considerations. Table 1 summarizes measurements taken during the March 15, 2022 site visit which were used to determine the design BFW. The measured BFW resulted in a **design average BFW of 5.5 feet.**

Table 1: Bankfull width measurements

BFW #	BFW Width (ft)	Distance from culvert (ft)	Included in Design Average	Concurrence Notes
1	6	295	Yes	No BFW concurrence meeting has occurred
2	3.7	250	Yes	No BFW concurrence meeting has occurred
3	4.5	200	Yes	No BFW concurrence meeting has occurred
4	5	150	Yes	No BFW concurrence meeting has occurred
5	6	100	Yes	No BFW concurrence meeting has occurred
6	8	50	Yes	No BFW concurrence meeting has occurred
Design Average	**5.5**			**No BFW concurrence meeting has occurred**

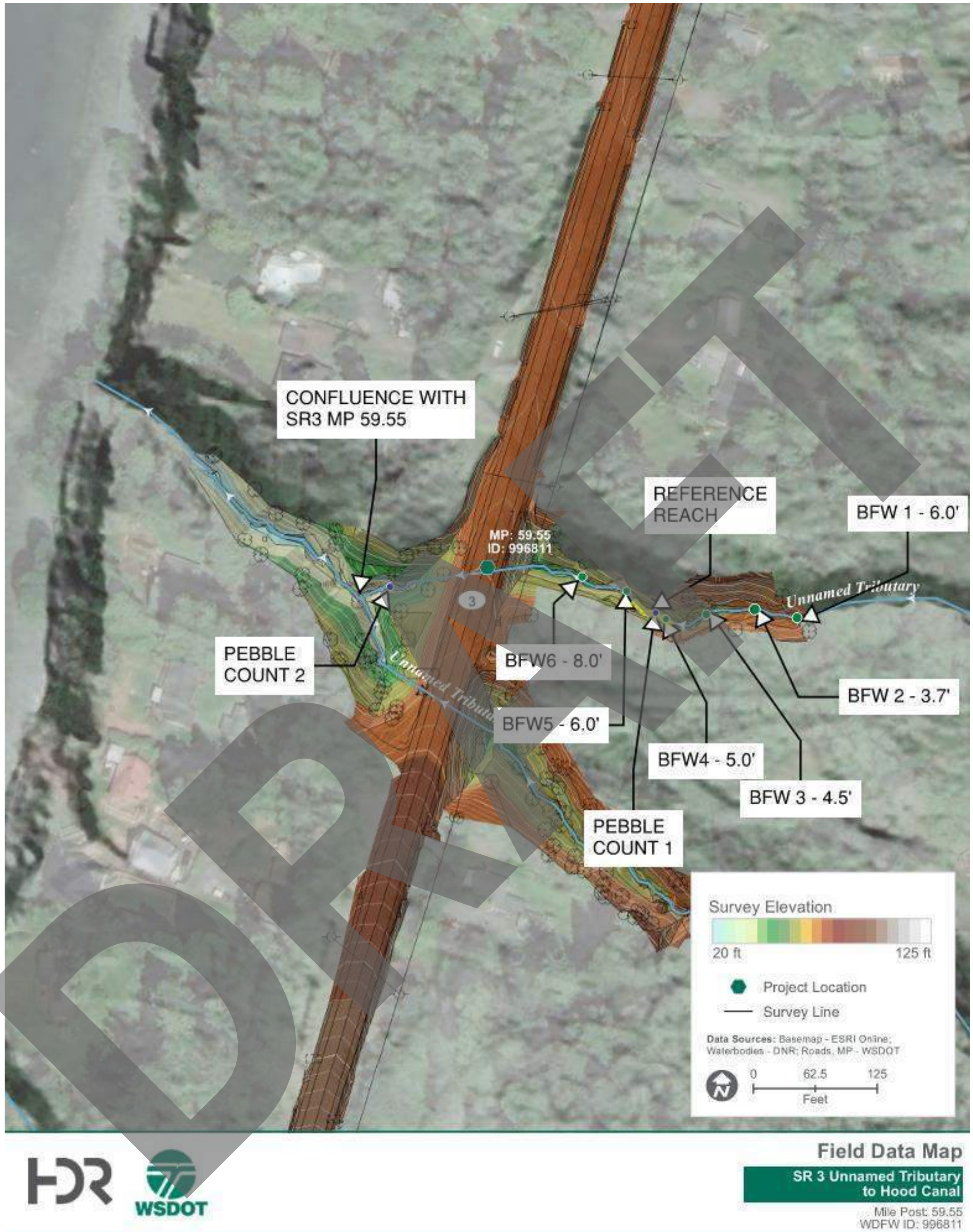


Figure 1: Reference reach, BFW, and pebble count locations

Reference Reach:

Describe location, known history, summarize on site discussion, appropriateness, bankfull measurement, geomorphic pattern, slope.

One potential reference reach approximately 40 feet long was identified spanning from approximately 120 to 160 feet to upstream of the culvert inlet, as shown in Figure 1. Cross section geometry in the reference reach will be used to inform the channel design. A pebble count and BFW were taken in the potential reference reach. This location was selected as a potential reference reach because it is outside of the influence of the culvert. Photographs of each BFW width measurement are provided in Figure 6, Figure 8, Figure 14, Figure 15, Figure 17, and Figure 20. A second site visit with HDR, WSDOT, WDFW, and the tribes has not yet been conducted to gain concurrence on reference reach location.

Data Collection:

Describe site conditions, channel geomorphology (shape, spacing of features, etc), habitat type and location, flow splits, LWM location and quantity, etc. Provide a sketch showing location of data collected.

HDR conducted an independent site visit on March 15, 2022. HDR walked the stream approximately 300 feet upstream and approximately 60 feet downstream of the existing culvert crossing. HDR took six BFWs and one pebble count upstream of the culvert crossing, and one pebble count downstream of the crossing.

The following paragraphs and figures describe field observations of UNT to Hood Canal from upstream to downstream. Figure 2 shows a field sketch of a plan view and cross sections of the UNT to Hood Canal upstream and downstream of the crossing. The stationing in the upstream (US) reach starts at station (STA) 0+00 at the culvert inlet and increases from downstream to upstream. Downstream (DS), the stationing starts at 0+00 at the culvert outlet and increases heading downstream.

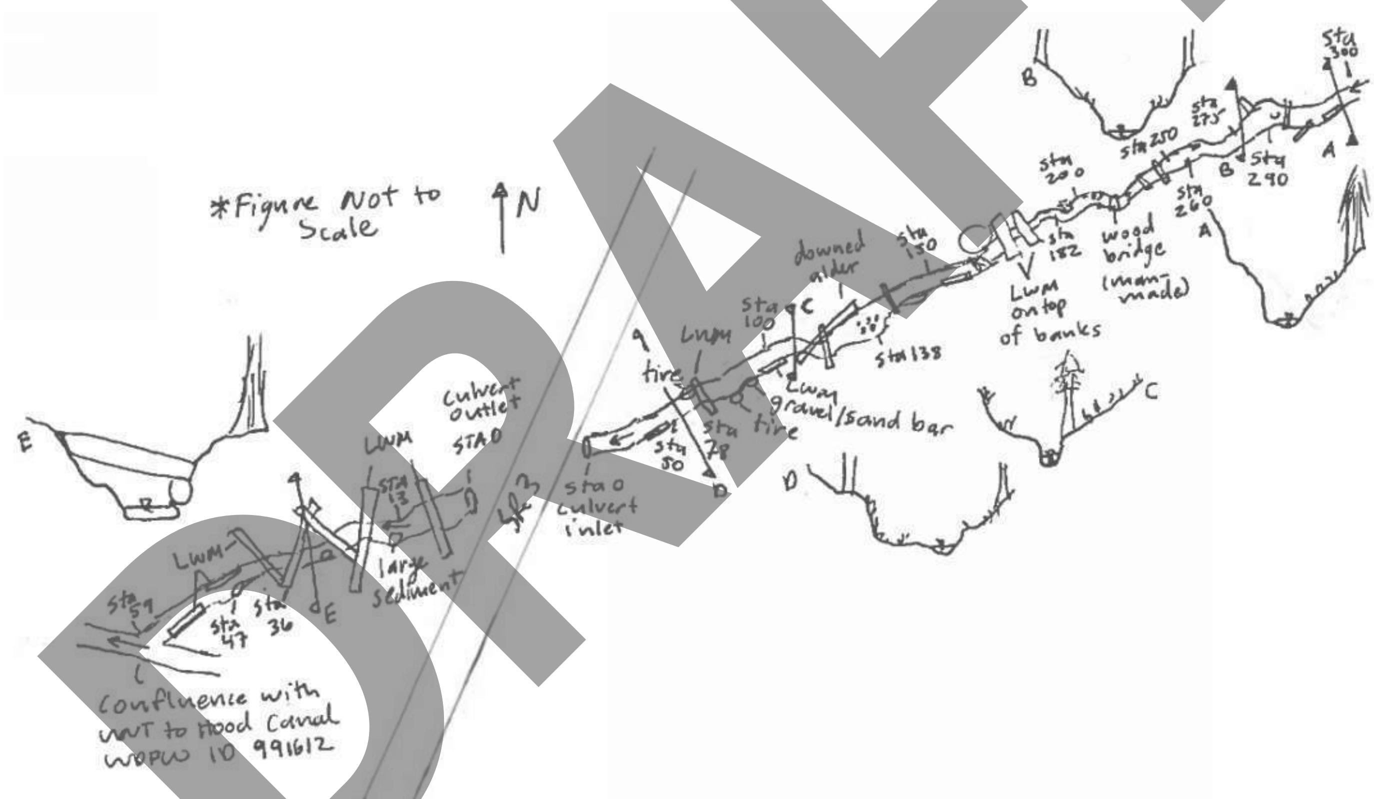


Figure 2: Plan view and cross sections of UNT to Hood Canal

Upstream Reach

From the culvert inlet to 300 feet upstream of the inlet, the channel is relatively consistent. In this reach the stream is a well-defined, single threaded channel with abundant small and large woody material (LWM). The overall planform is straight, but within the straight path the reach has tight bends and meanders largely influenced by woody material. The small woody material is less than a foot in diameter and forms natural steps. The channel has a step-pool morphology is forced by LWM and to a lesser extent, large cobbles. The cross-sectional channel shape is frequently non-uniform and characterized by a meandering thalweg directed by woody material or sediment deposits. Where there is no woody material, the channel shape is uniform and U-shaped within defined banks. The bed throughout the upstream reach is comprised of small gravels and sand, with some small cobbles observed. The channel is confined within banks that vary from steeply sloping to vertical one- to three-foot-high banks. The top of bank to the valley toe is generally steep and sparsely vegetated by ferns and small trees. Large mature trees were abundant between the valley toe and top of bank. Variability within these general characteristics in the upstream reach is described in the subsequent paragraphs moving from upstream to downstream.

The field reconnaissance survey began approximately 300 feet upstream of the culvert inlet. Here, the channel shows signs of incision with approximately a three-foot vertical left bank and is undercut with LWM positioned parallel to the flow along the left bank. Smaller woody debris (Figure 5) is scattered throughout a small section between STA 2+90 and 3+00 that act as steps. At STA 2+90 the channel bed is comprised of a range of particles from sand to cobbles (Figure 7). The cobbles and small woody debris force the thalweg to meander. The channel and bank interactions start to vary as the left bank has an accessible floodplain at STA 2+75. As the channel meanders back and forth, the accessible floodplain varies from right to left and the right bank has an accessible floodplain at STA 2+60. The channel bed changes slightly further downstream as the cobbles decrease and sand and fines abundance increase at STA 2+50 (Figure 9). Small woody debris abundance also increases in this area creating step like features (Figure 10) and shifts the thalweg from the right to left bank. Banks are incised approximately 1 foot here. At approximately STA 2+25 a small man-made plank (Figure 11) acts as a bridge across the stream, spanning across the banks. At STA 2+00 the floodplains narrow and the banks are more incised with vertical drops of one to two feet. Immediately upstream of STA 1+82, a bar with small cobbles and large gravels forms on the inside of a bend on the right bank. From approximately STA 1+82 to 1+62 the river flows under a natural bridge made by two LWM pieces spanning across the banks (Figure 12). Soil and debris have accumulated on top of the LWM pieces, forming a partially enclosed natural bridge, forcing flow underneath and influencing channel shape. BFW measurements were taken outside of the influence of this feature. At the exit of the natural bridge, the water surface drops approximately one foot over small woody material and a drop in the channel bed.

Downstream of the drop, the thalweg is shifted to the left bank by a large alder and its roots occupying the right bank. The flow continues along the left side of the channel, flowing over a piece of wood that has been embedded within the channel. It makes up the channel bed for approximately 10 feet (Figure 13). At STA 1+50 the left bank is nearly vertical. From approximately STA 1+82 to STA 1+40 the bed is comprised mostly of sands and fines with the exception of a gravel and sand bar on the left bank at STA 1+45. At STA 1+40 the channel widens and small cobbles become abundant and the banks are not incised (Figure 16). A D100 value of 10 inches was measured at STA 1+38. At STA 1+30 the channel narrows again and a downed alder lines the right bank and crosses the channel at STA 1+15 as the channel meanders to the right, and the banks narrow (Figure 18). Downstream of STA 1+00 the bed is comprised of cobbles, gravels, sand and fines and LWM parallels the left bank. At STA 0+90 a gravel and sand bar forms on the left bank and the channel continues with no access to the floodplain with approximately two foot high vertical and narrow banks. At STA 0+78 a 1.5 foot diameter downed tree spans across the banks of the channel (Figure 19) and approximately 15 feet further downstream another downed tree with a diameter of 1 foot spans the banks. Two tires were observed in this section of the stream on the left and right bank. At STA 0+50 the channel floodplains become wider and become more accessible on the right bank. Approaching the culvert inlet (Figure 21), the stream cascades down at a steep slope through woody material and cobbles from STA 0+00 to 0+06 before entering the culvert. A small inflow from road drainage was observed on the right bank at STA 0+00.

Downstream Reach

The downstream reach is similar to the upstream reach but is characterized by larger LWM approximately 2 to 3 feet in diameter, spanning the channel banks and has larger step-pool features, and a more incised channel than upstream (Figure 22).

The culvert outlets into a scour pool (Figure 23) with the right and left bank undercut in the vicinity of the outlet (Figure 24). Immediately downstream of the outlet LWM spans over the banks and the bed is comprised of sand and gravel (Figure 25). After traveling under the LWM the flow follows the right bank at STA 0+13, directed away from the left bank by small woody material and large cobble. Downstream of the cascade, the flow travels under four more LWM pieces through STA 0+36 (Figure 26). The LWM spans the banks, which are approximately one to two feet incised. Through this section of the reach, the channel is comprised of mostly gravels and sand with some cobbles. The channel continues to cascade through the cobbles and woody material for another 20 feet before dropping approximately 16 inches on the left side of the channel as flow is directed away from the right bank by cobbles and small woody material (Figure 27). After the drop the channel travels through a flatter section and the bed is comprised of gravel and sand. Hard pan is present on the left bank at STA 0+45 (Figure 28). LWM parallels the left bank immediately before the downstream segment ends at STA 0+59 at the confluence with UNT to Hood Canal.

Pebble Counts:

Describe location of pebble counts if available.

Wolman pebble counts were conducted at two locations: one upstream of SR 3, with approximately 200 particles, and one downstream of SR 3 with approximately 100 particles. The upstream pebble count was completed in the upstream reference reach, shown in Figure 1 above. The pebble count in the reference reach was taken because of the similar material size observed throughout the channel. The downstream pebble count was taken to capture the range of material sizes throughout the site. The cumulative distribution and specific pebble sediment sizes are provided in Figure 3 and Table 2. Material primarily consisted of sand, gravel and small cobbles as shown in Figure 4.

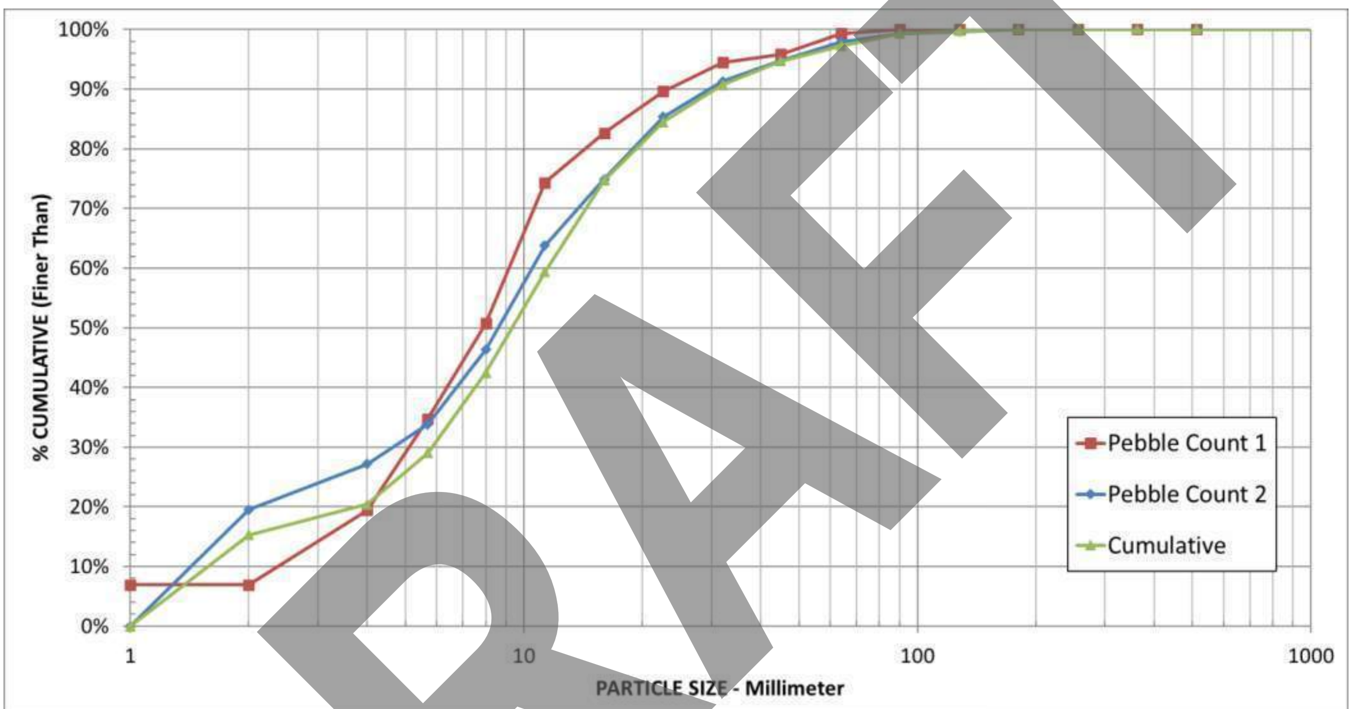


Figure 3: Sediment size distribution

Table 2: Sediment properties

Particle	Pebble Count 1 Diameter (upstream) (in)	Pebble Count 2 Diameter (downstream) (in)	Cumulative Diameter (in)
D_{16}	0.1	0.2	0.1
D_{50}	0.3	0.4	0.4
D_{84}	0.9	0.9	0.9
D_{95}	1.8	2.0	1.9
D_{100}	7.1	5.0	7.1

Figure 4: Representation of typical channel substrate

Photos:

Any relevant photographs placed here with descriptions.


Figure 5: Small woody material at STA 3+00 (looking across channel at the left bank)


Figure 6: BFW #1 measurement and stream condition (looking upstream)

Figure 7: Streambed material and shape looking downstream of STA 2+90 (looking downstream)

Figure 8: BFW #2 measurement and stream location (looking downstream)

Figure 9: STA 2+50 channel and bed composition (looking downstream)


Figure 10: Looking upstream, small woody debris forming step like feature (looking upstream)


Figure 11: Plank across channel (upstream to the right of the photograph- looking at right bank)


Figure 12: Flow going under natural bridge at STA 1+82 (looking downstream)


Figure 13: LWM as channel bed on left bank (top of the page is downstream, picture facing left bank)


Figure 14: BFW #3 measurement and stream condition (looking downstream)


Figure 15: BFW #4 measurement and stream condition (looking downstream)

Figure 16: Cobbles and stream condition in reference reach (looking downstream)

Figure 17: BFW #5 measurement and stream condition (looking downstream)

Figure 18: LWM lining right bank and channel banks narrowing (looking downstream)

Figure 19: LWM spanning across banks (looking downstream)

Figure 20: BFW #6 measurement and stream condition (looking downstream)

Figure 21: Culvert inlet at SR 3 WDFW ID 996811 (looking downstream)

Figure 22: General channel characteristics downstream (looking upstream)

Figure 23: Culvert outlet at SR 3 WDFW ID 996811 (looking upstream)

Figure 24: Undercut bank at scour outlet (looking upstream at right bank)

Figure 25: LWM spanning across bank downstream of culvert outlet (looking downstream)


Figure 26: LWM spanning across channel (looking upstream)


Figure 27: 16-inch drop from the right to the left side of the channel (looking upstream)

Figure 28: Hardpan on left bank (looking upstream)

Samples:	
Work within the wetted perimeter may only occur during the time periods authorized in the APP ID 21036 entitled "Allowable Freshwater Work Times May 2018". Work outside of the wetted perimeter may occur year-round. APPS website: https://www.govonlinesaas.com/WA/WDFW/Public/Client/WA_WDFW/Shared/Pages/Main/Login.aspx	
Were any sample(s) collected from below the OHWM?	*No ☒ If no, then stop here.*
	Yes ☐ If yes, then fill out the proceeding section for each sample; as well as log the sample for GHPA annual reporting in the 202x Fish Passage Streambed Sediment Sample Log spreadsheet located on ProjectWise ***Field Resources*** *folder.*

Sample #:	Work Start:	Work End:	Latitude:	Longitude:

Summary/description of location:

Summarize/describe the sample location.

Description of work below the OHWL:

Describe the work below the OHWL, including equipment used and quantity of sediment sampled.

Description of problems encountered:

Describe any problems encountered, such as provision violations, notification, corrective action, and impacts to fish life and water quality from problems that arose.

WSDOT Hydraulics Section	Project Complexity Field Form	Prepared By: Cade Roler	Page: 1
	Project Name: WSDOT Olympic Region GEC- Task Order AC	Date: 4/27/2022	
	Stream Name: UNT	WDFW ID Number: 996811	
	Tributary to: Hood Canal	State Route/MP: SR 3/MP 59.55	

Site Visit Type:

Resource Co-manager Site Visit

Anticipated Level of Complexity:

Low ☐ Medium: ☒ High: ☐

Additional Notes:

In Water Work Window: Need from WDFW
General Instructions: The following elements of projects should be discussed before the production of a Preliminary Hydraulic Design by members of WSDOT and WDFW to identify the level of complexity for each site, and corresponding communication and review. While certain elements may be categorized as indicators of a low/medium/high complexity project, these are only suggestions, and newly acquired information may change the level of complexity during a project. The ultimate documentation category for a given site is up to both WSDOT and WDFW, considering both site characteristics and synergistic effects. Discuss the following elements as they apply to the project. Rank each element as low, medium, or high in complexity. The assigned level of complexity determines the appropriate agreed upon review from WDFW (*see accompanying document, coming soon*). Ultimately, WSDOT needs to acquire an HPA from WDFW for fish passage projects and the agreed upon communication and review of project elements will contribute to efficiencies in the permitting process.

Category	Project Elements	Levels of Complexity			Follow up/Observations
		Low	Med	High	
Stream Design Factors (alignment, profile, bed mix)	Channel realignment	X			
	Stream grading extents		X		
	Expected stream movement (migration)	X			
	Gradient (morphology)			X	
	Slope ratio		X		
	Sediment supply	X			

WSDOT Hydraulics Section	Project Complexity Field Form	Prepared By: Cade Roler	Page: 2
	Project Name: WSDOT Olympic Region GEC- Task Order AC	Date: 4/27/2022	
	Stream Name: UNT	WDFW ID Number: 996811	
	Tributary to: Hood Canal	State Route/MP: SR 3/MP 59.55	

Category	Project Elements	Levels of Complexity			Follow up/Observations
		Low	Med	High	
Structure Factors	Stream size and bankfull width	X			
	Meeting requirements for freeboard	X			
	Fill depth above barrier		X		
	Risk of degradation/aggradation			X	
	Long culvert criteria/openness ratio		X		
	Channel confinement & Floodplain Utilization Ratio (FUR)	X			
	Meeting Stream Simulation		X		Challenge with step pools
	Tidal influence	X			N/A
	Alluvial fan	X			
	Presence of other barriers nearby		X		Diversion dam downstream could lead to degradation if removed
	Potential for backwater impacts	X			
	Presence of infrastructure nearby	X			
	Need for bank protection			X	Steep ravine
	Geotech or seismic considerations			X	No scoping memo yet

WSDOT Hydraulics Section	Site Visit 3 Field Report	Project Number: Y-12554
	Project Name: WSDOT Olympic Region GEC- Task Order AC	Date: 4/27/2022
	Project Office: Pre-Design Office	Time of Arrival: 9:13am
	Stream Name: UNT	Time of Departure: 11:15am
WDFW ID Number: 996811	Tributary to: Hood Canal	Weather: Sunny, 60° F
State Route/MP: SR 3/MP 59.55	Township/Range/Section/ ¼ Section: T27N/R1E/S12/NW	Prepared By: Cade Roler
County: Kitsap	Purpose of Site Visit: Co-manager site visit	WRIA: 15

Meeting Location:

UNT to Hood Canal, SR 3, MP 59.55

Additional Data Collection:

A second site visit with HDR, WSDOT, and WDFW was conducted April 27, 2022 to gain concurrence on BFWs and other design considerations. Tribal representatives were invited to the site visit but were unable to attend. Site visit participants observed sediment and small debris deposition at the inlet of the existing culvert inlet. Participants walked 300 feet upstream of the existing inlet and collected stream measurements moving downstream through the reference reach. The group collected additional BFW measurements, valley width measurements, and water surface drops at various steps (see Figure 29-37). Site visit participants then walked downstream of the existing culvert to the confluence of the left bank tributary and collected water surface drops working back upstream.

Ten new BFW's were measured upstream based on the observed grade breaks in the stream. The average BFW from the new ten measurements and previous BFW 1 measurement results in a design average of 6 feet. During the site visit participants also measured valley widths at multiple locations through the reference reach. Valley widths were measured between toe and top of the valley to ensure that measurement captured potential meander planform. Valley width measurements ranged between 20.5 feet and 34 feet with an average width of 25 feet. The agreed upon complexity level is medium.

Observations:

During the site visit participants discussed channel shape, morphology and deformability of the observed steps. Steps were observed to be highly deformable consisting mainly of coarse cobbles with small debris accumulations. It is likely that the steps are re-arranged after high flows. The group measured water surface drops at multiple locations on the upstream and downstream channel.

Upstream Measured Steps (Distance from culvert inlet):
250 ft Upstream – 0.5 feet: Deformable step consisting of small debris accumulation on porous stone line
239 ft Upstream – 0.3 feet: Deformable step consisting of small debris accumulation.
234 ft Upstream – 0.3 feet: Deformable step consisting of small debris accumulation.
170 ft Upstream – 0.7 feet: Drop of debris accumulations on large root systems. This is a less deformable step.
109 ft Upstream – 0.3 feet: Deformable step consisting of small debris accumulation.
50 ft Upstream – 0.4 feet: Deformable step consisting of small debris accumulation.

Downstream Measured Steps (Distance from culvert outlet):
50 ft Downstream – 0.6 feet: Deformable step consisting of small debris accumulation.
40 ft Downstream – 0.8 feet: Deformable step consisting of small debris accumulation and coarse cobbles.
35 ft Downstream – 0.7 feet: Deformable step consisting of small debris accumulation and coarse cobbles.
20 ft Downstream – 0.9 feet: Accumulation of larger wood debris

It was also discussed on site that the WDFW WRIA Catalog shows that historically there was a cascade section through the reach immediately downstream and upstream of SR 3 at this crossing and the adjacent barrier 991612.

Photos:

Any relevant photographs placed here with descriptions.

Figure 29 Small steps through reference reach with small debris accumulations and bank erosion through the confined valley.

Figure 30 Series of drops observed with coarse cobbles and debris accumulations in reference reach

Figure 31 New BFW in reference reach

Figure 32 Debris drop in reference reach

Figure 33 Series of debris drops through reference reach

Figure 34 Additional BFW measurement through reference reach


Figure 35 Additional BFW measurement downstream of reference reach


Figure 36 Downstream drop formed by debris, cobbles and a large immobile boulder

Figure 37 Downstream drop formed by debris and cobbles

WSDOT Hydraulics Section	Site Visit 3 Concurrence Form	Prepared By: Cade Roler
	Project Name: WSDOT Olympic Region GEC- Task Order AC	Date: 4/27/2022
	Stream Name: UNT	WDFW ID Number: 996811
	Tributary to: Hood Canal	State Route/MP: SR 3/MP 59.55

Bankfull Measurements:

Location	Width	Include in Average?
BFW 1: 295	5.3 feet	Yes
BFW 2 (new): 280	6 feet	Yes
BFW 3 (new): 274	5.4 feet	Yes
BFW 4 (new): 263	6.5 feet	Yes
BFW 5 (Previously BFW 2): 250	3.5 feet	Yes
BFW 6 (Previously BFW 3): 200	4.5 feet	Yes
BFW 6 (new): 198 ft	6.3 feet	Yes
BFW 8 (Previously BFW 4): 150	6.3 feet	Yes
BFW 9 (new): 139	7.9 feet	Yes
BFW 10 (Previously BFW 5): 100	7.1 feet	Yes
BFW 11(Previously BFW 6): 50	6.7 feet	Yes

Additional Notes:

No BFW measurements were taken downstream. Downstream is highly incised and not representative of the overall reach

Average Bankfull Width: 6ft **Concurrence Reached:** Yes: ☒ No: ☐

Reference Reach Location and Morphology:

An appropriate reference reach was identified and agreed upon approximately 120 to 160 feet upstream of the existing culvert inlet. The group concurred that the natural morphology within the reference reach consists of step pool with sections of pool-riffle between step series.

Reference Reach Morphology: Step Pool with Pool-riffle between steps **Concurrence Reached:** Yes: ☒ No: ☐

Habitat Connectivity:

Habitat Connectivity Memo: Received or In Process ☐ Requested ☐ Not Requested ☒

Additional Notes:

Additional Information Requested by Comanagers:

WDFW requested additional information and discussion on step pool design and potentially designing deformable steps. WDFW also noted the existence of an eagle's nest in the vicinity of the crossing and wanted this noted for permitting purposes. It was also noted by WSDOT that WDFW's WRIA catalog shows the existence of natural cascades at the existing culvert location indicating steeper gradients through the reach.

Project Next Steps/Additional Notes:

Next steps will be to have additional discussions regarding step pool design and whether they will be designed to be deformable or rigid as recommended in WDFW's Water Crossing Design Guidelines.

Comanager/WSDOT/Hydraulic Lead Initials:

Name	Organization	Initials	Name	Organization	Initials
Brittany Gordon	WSDOT	[illegible]			
Amber Martens	WDFW	Am			
Kristin LaForge	HDR	KL			

WSDOT Hydraulics Section	Site Visit 3 Attendance List	Prepared By: Cade Roler
	Project Name: WSDOT Olympic Region GEC- Task Order AC	Date: 4/27/2022
	Stream Name: UNT	WDFW ID Number: 996811
	Tributary to: Hood Canal	State Route/MP: SR 3/MP 59.55

Bankfull Measurements:

Name	Agency/Tribe/Firm	E-mail	Present
Damon Romero	WSDOT	RomeroD@WSDOT.WA.GOV	Yes
Kate Fauver	WSDOT	fauverk@wsdot.wa.gov	Yes
Dave Molenaar	WSDOT	MolenaD@WSDOT.WA.GOV	Yes
Amber Martens	WDFW	Amber.Martens@dfw.wa.gov	Yes
Brittany Gordon	WSDOT	GordoBr@WSDOT.WA.GOV	Yes
Kristin LaForge	HDR	Kristin.LaForge@hdrinc.com	Yes
Cade Roler	HDR	Cade.Roler@hdrinc.com	Yes

Appendix C: Streambed Material Sizing Calculations

Summary - Stream Simulation Bed Material Design

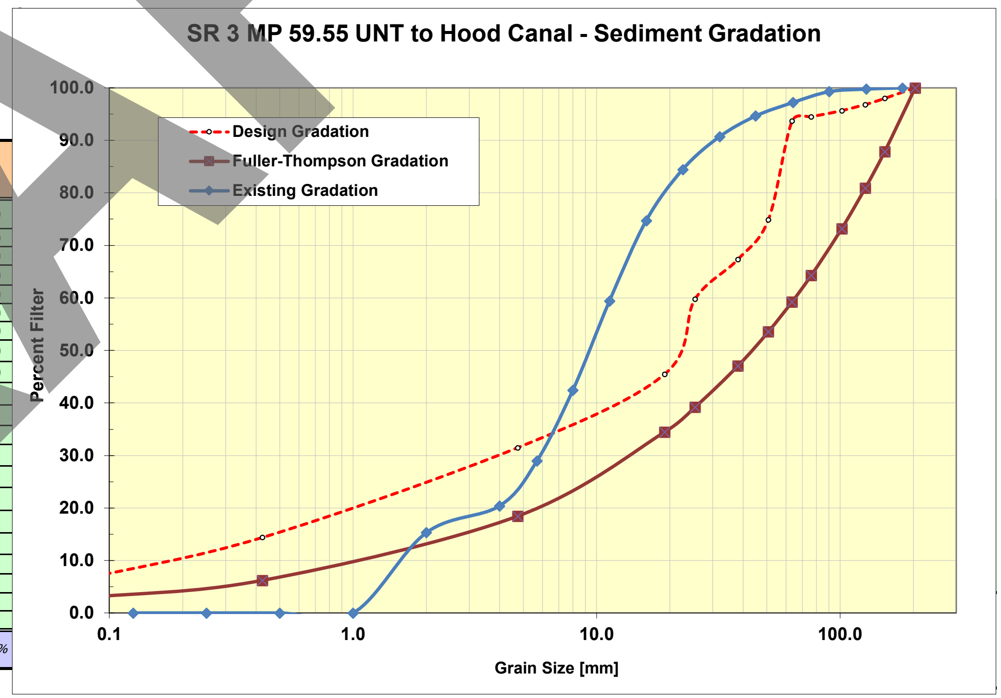
Project:	WSDOT SR 3 MP 59.55 UNT to Hood Canal
By:	Kristin LaForge

Observed Gradation:						*Design Gradation*					
Location:						Location:	Streambed Design				
	D_{100}	D_{95}	D_{84}	D_{50}	D_{16}		D_{100}	D_{95}	D_{84}	D_{50}	D_{16}
ft	0.6	0.2	0.1	0.0	0.0	ft	0.67	0.28	0.19	0.07	0.00
in	7.1	1.9	0.9	0.4	0.1	in	8.0	3.4	2.2	0.8	0.0
mm	180	47	22	9.4	2.0	mm	203	86	57	20.9	0.5

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				98.0
5.0	127			80	68	57	45				96.8
4.0	102		100	71	57	45	39				95.7
3.0	76.2		80	63	45	38	34				94.5
2.5	63.5	100	65	54	37	32	28				93.7
2.0	50.8	80	50	45	29	25	22				74.9
1.5	38.1	73	35	32	21	18	16				67.4
1.0	25.4	65	20	18	13	12	11				59.8
0.75	19.1	50	5	5	5	5	5				45.5
0.187	4.75	35									31.5
No. 40 =	0.425	16									14.4
No. 200 =	0.0750	7									6.3
% per category		90	0	0	10	0	0	0	0	0	--> 100%



Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Summary - Step Crest Design

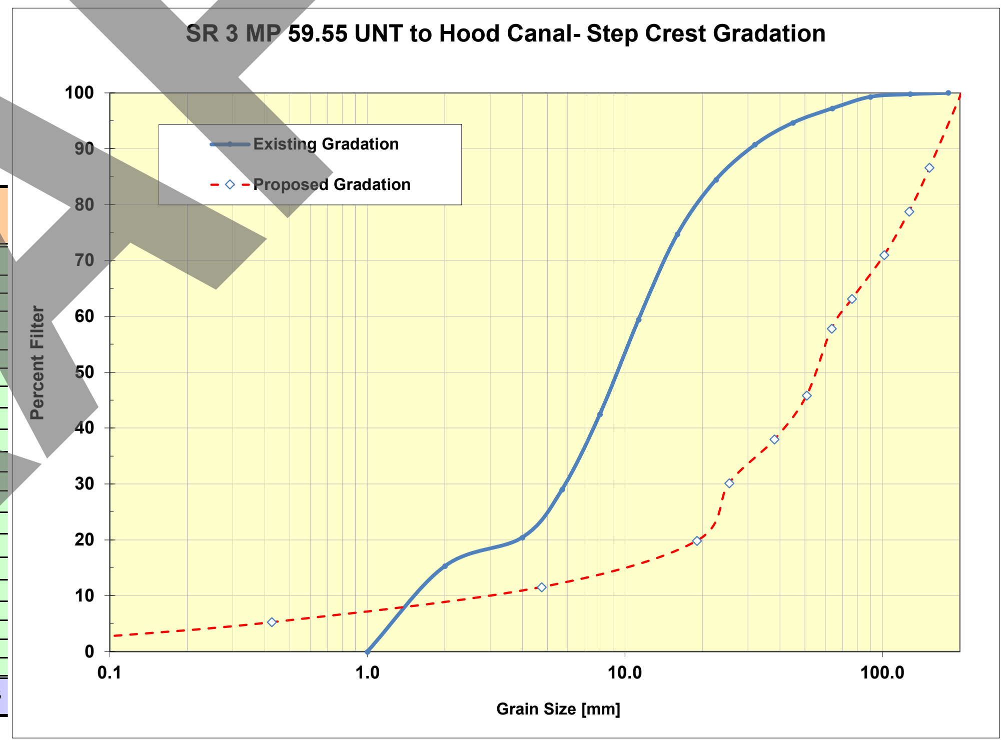
Project:	WSDOT SR 3 MP 59.55 UNT to Hood Canal
By:	Kristin LaForge

Observed Streambed Material					*Design Gradation*					
Location:	Reference Reach				Location:	Step crest design				
	D_{100}	D_{84}	D_{50}	D_{16}		D_{100}	D_{95}	D_{84}	D_{50}	D_{16}
ft	0.6	0.1	0.0	0.0	ft	0.67	0.60	0.47	0.18	0.03
in	7.1	0.9	0.4	0.1	in	8.0	7.2	5.6	2.2	0.4
mm	180	23	10.2	2.0	mm	203	183	142	56	10

Determining Aggregate Proportions

Per WSDOT Standard Specifications 9-03.11

Rock Size [in]	Rock Size [mm]	Streambed Sediment	Streambed Cobbles 4"	6"	8"	10"	12"	Streambed Boulders 12"-18"	18"-28"	28"-36"	D_{size}
36.0	914									100	100.0
32.0	813									50	100.0
28.0	711								100		100.0
23.0	584								50		100.0
18.0	457							100			100.0
15.0	381							50			100.0
12.0	305						100				100.0
10.0	254					100	80				100.0
8.0	203				100	80	68				100.0
6.0	152			100	80	68	57				86.6
5.0	127			80	68	57	45				78.8
4.0	102		100	71	57	45	39				71.0
3.0	76.2		80	63	45	38	34				63.2
2.5	63.5	100	65	54	37	32	28				57.8
2.0	50.8	80	50	45	29	25	22				45.8
1.5	38.1	73	35	32	21	18	16				38.0
1.0	25.4	65	20	18	13	12	11				30.2
0.75	19.1	50	5	5	5	5	5				19.9
0.187	4.75	35									11.6
No. 40 =	0.425	16									5.3
No. 200 =	0.0750	7									2.3
% per category		33	0	0	67	0	0	0	0	0	--> 100%



Otto Gershon, gershoo@wsdot.wa.gov ; 9/2007
modified by Kevin Lautz, P.E. 6/2010

Bathurst Unit Discharge Method Calculations

2-yr Stability Threshold	
q (cfs/ft)	0.6
g	32.2
Slope (ft/ft)	0.080
BFW based on modeling (ft)	3.0
Flow (2 yr)	1.8
d84 (ft)	0.1
d16 (in)	0.2
d50 (in)	0.7
Stable d84 (in)	**1.7**
d100 (in)	4.2

100-yr Stability Threshold	
q (cfs/ft)	2.1
g	32.2
Slope (ft/ft)	0.080
BFW based on modeling (ft)	3.0
Flow (2 yr)	6.3
d84 (ft)	0.3
d16 (in)	0.5
d50 (in)	1.5
Stable d84 (in)	**3.9**
d100 (in)	9.6

2080 100-yr Stability Threshold	
q (cfs/ft)	3.0
g	32.2
Slope (ft/ft)	0.080
BFW based on modeling (ft)	3.0
Flow (2 yr)	9.1
d84 (ft)	0.4
d16 (in)	0.6
d50 (in)	2.0
Stable d84 (in)	**4.9**
d100 (in)	12.3

Formula Used	
See screenshot below	Bathurst 1987
d84/8	Barnard et. al 2013
d84/2.5	Barnard et. al 2013
d84/0.4	Barnard et. al 2013

$$D_{84} = 3.54 S^{0.747} (1.25 q_c)^{2/3} / g^{1/3}$$ **Equation 3.3**

Where:

D_{84} = intermediate axis of the 84th percentile particle in the sediment distribution, expressed in feet

S = energy slope of the proposed channel, ft/ft.

q_c = the critical unit discharge (total design discharge divided by the width of the bankfull channel) at which incipient motion of D84 occurs, in cubic feet per second per foot.

G = The acceleration due to gravity, feet/sec^2.

Bathurst, J.C. (1987). "Critical conditions for bed material movement in steep, boulder-bed streams." International Association of Hydrological Sciences Publication 165: 309-318.

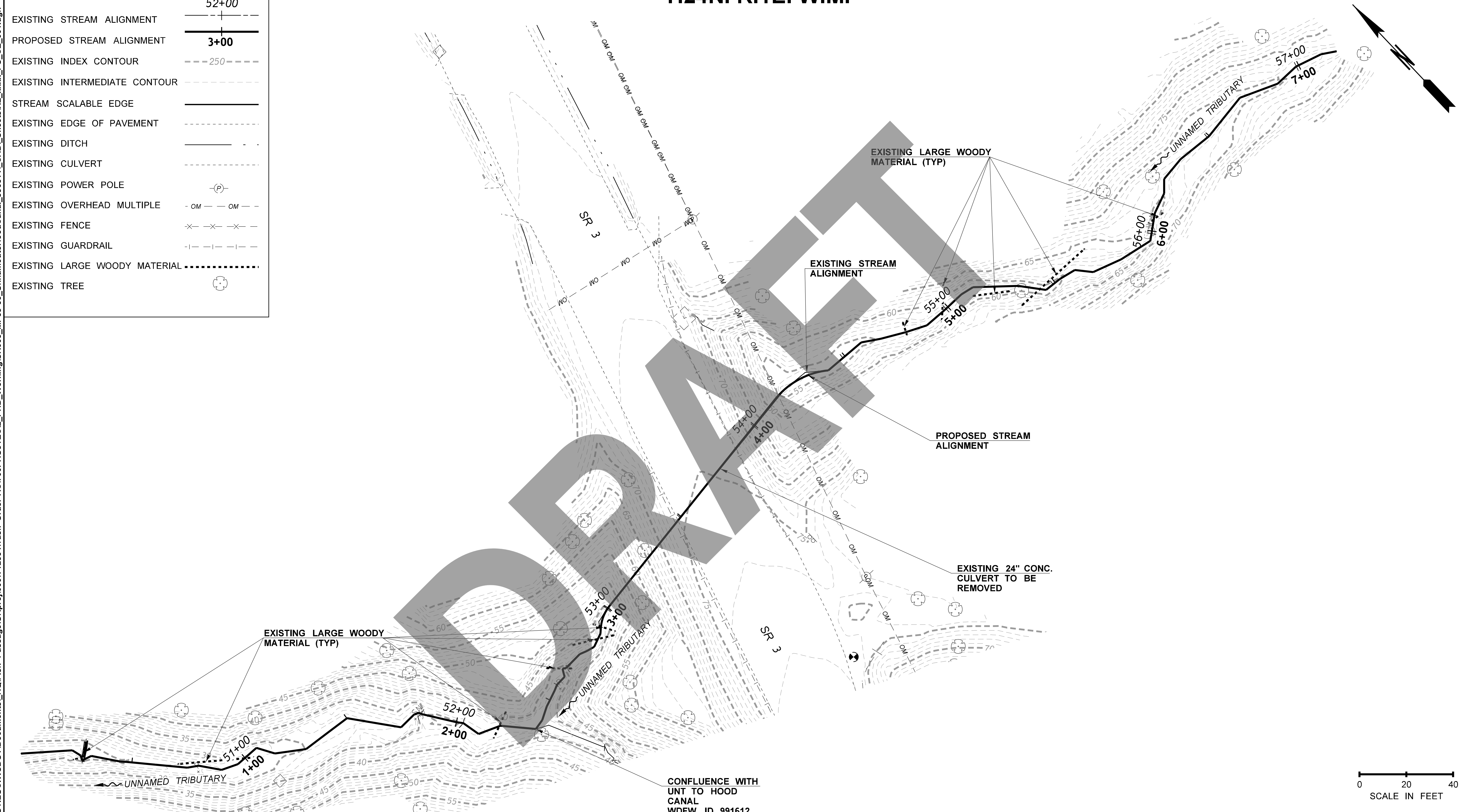
Barnard, R.J., J. Johnson, P. Brooks, K.M. Bates, B. Heiner, J.P. Klavas, D.C. Ponder, P.D. Smith, and P.D. Powers. 2013. Water Crossing Design Guidelines. Washington State Department of Fish and Wildlife. Olympia, Washington.

Appendix D: Stream Plan Sheets, Profile, Details

T.24N. R.1E. W.M.

LEGEND

EXISTING STREAM ALIGNMENT	52+00
PROPOSED STREAM ALIGNMENT	3+00
EXISTING INDEX CONTOUR	250
EXISTING INTERMEDIATE CONTOUR	
STREAM SCALABLE EDGE	
EXISTING EDGE OF PAVEMENT	
EXISTING DITCH	
EXISTING CULVERT	
EXISTING POWER POLE	P
EXISTING OVERHEAD MULTIPLE	OM — OM
EXISTING FENCE	
EXISTING GUARDRAIL	
EXISTING LARGE WOODY MATERIAL	
EXISTING TREE	



PRELIMINARY - NOT FOR CONSTRUCTION

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PLOTTED BY	Mike Keilbart
DESIGNED BY	K. LAFORGE
ENTERED BY	M. KEILBART
CHECKED BY	J. HEILMAN
PROJ. ENGR.	J. METTLER
REGIONAL ADM.	

REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL_____

P.E. STAMP BOX — DATE

P.E. STAMP BOX — DATE

Washington State Department of Transportation

SR 3 MP 59.55
UNNAMED TO HOOD CANAL
FISH BARRIER REMOVAL

EXISTING STREAM PLAN

PLAN REF NO CE1

SHEET 1 OF 4 SHEETS

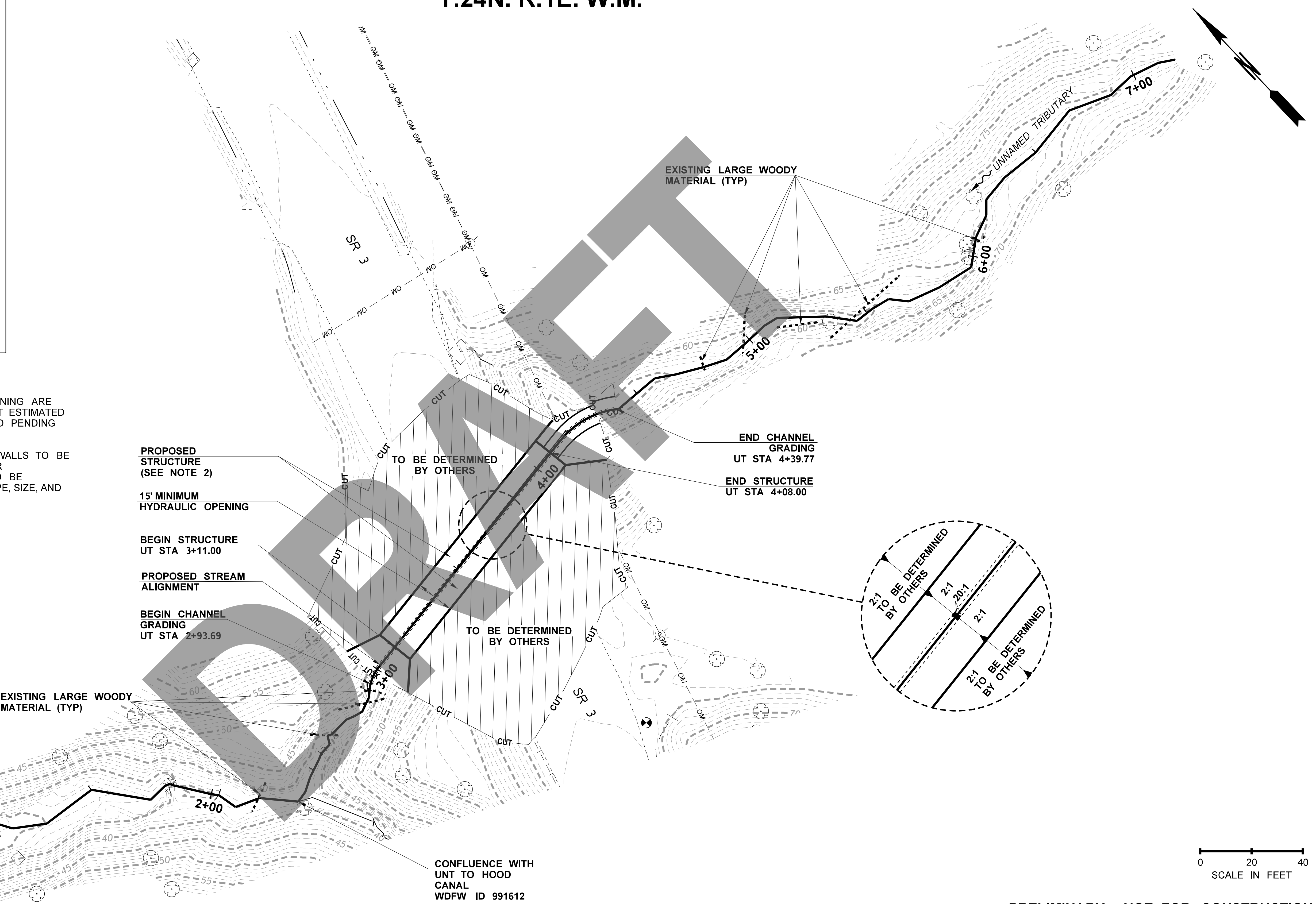
T.24N. R.1E. W.M.

LEGEND

EXISTING STREAM ALIGNMENT	52+00
NEW STREAM ALIGNMENT	5+00
EXISTING INDEX CONTOUR	250
EXISTING INTERMEDIATE CONTOUR	
STREAM SCALABLE EDGE	
EXISTING EDGE OF PAVEMENT	
EXISTING DITCH	
EXISTING CULVERT	
EXISTING POWER POLE	P
EXISTING OVERHEAD MULTIPLE	OM — — OM
EXISTING FENCE	
EXISTING GUARDRAIL	
EXISTING LARGE WOODY MATERIAL	
EXISTING TREE	

NOTES:

1. SLOPES SHOWN OUTSIDE THE HYDRAULIC OPENING ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACTTO BE DETERMINED PENDING GEOLOGICAL AND STRUCTURAL INVESTIGATION.
2. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED. GRADING LIMITS SHOWN ARE FOR ILLUSTRATIVE PURPOSES ONLY. FINAL LIMITS TO BE DETERMINED BASED ON FINAL STRUCTURE TYPE, SIZE, AND LOCATION.



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DESIGNED BY	K. LAFORGE		
ENTERED BY	M. KEILBART		
CHECKED BY	J. HEILMAN		
PROJ. ENGR.	J. METTLER		
REGIONAL ADM.	REVISION	DATE	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER XXXXX

CONTRACT NO. | LOCATION NO. XL_____

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

SR 3 MP 59.55
UNNAMED TO HOOD CANAL
FISH BARRIER REMOVAL

STREAM PLAN

PLAN REF NO CR1

SHEET 2 OF 4 SHEETS

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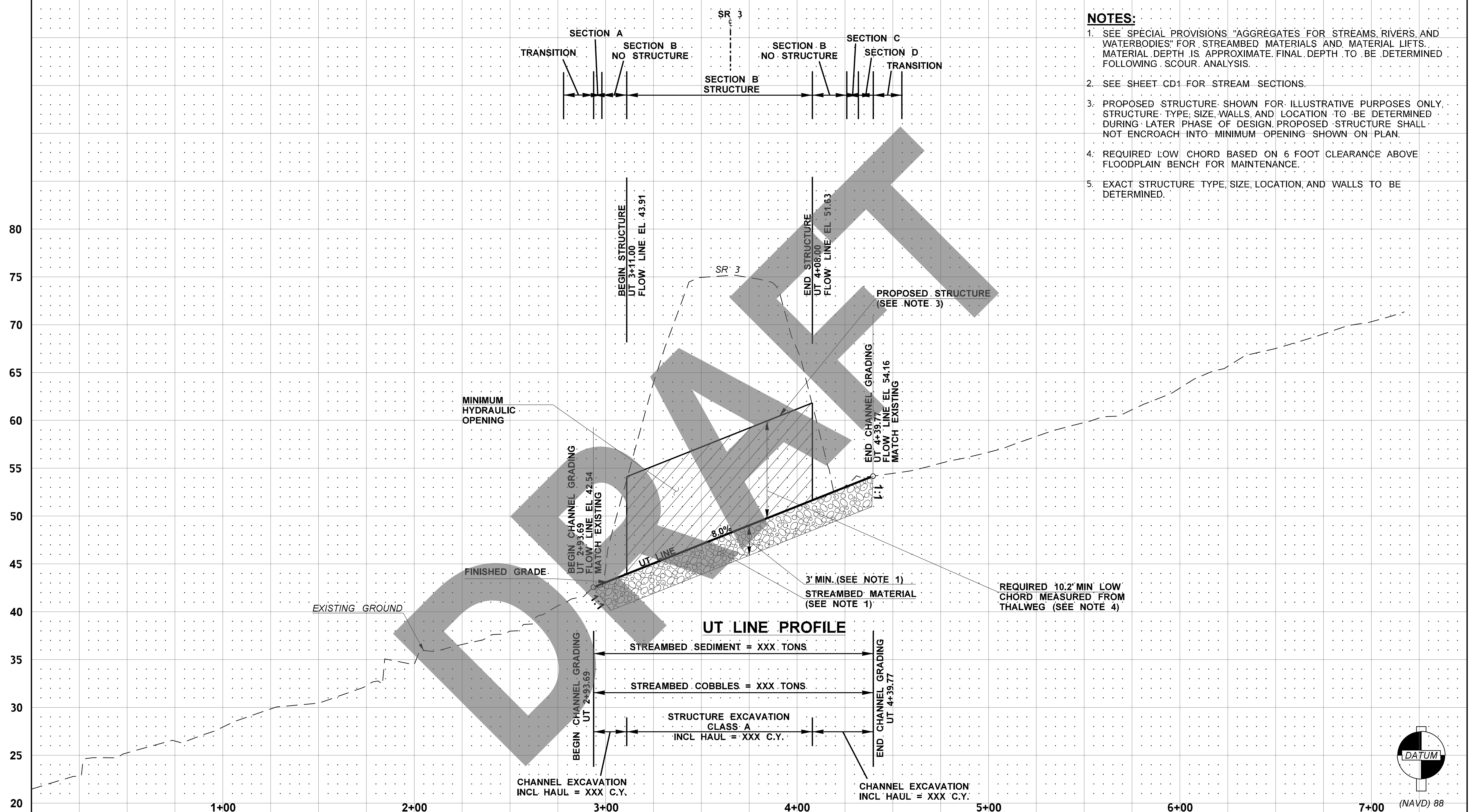
NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATES FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIALS AND MATERIAL LIFTS. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
2. SEE SHEET CD1 FOR STREAM SECTIONS.
3. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY, STRUCTURE TYPE, SIZE, WALLS, AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO MINIMUM OPENING SHOWN ON PLAN.
4. REQUIRED LOW CHORD BASED ON 6 FOOT CLEARANCE ABOVE FLOODPLAIN BENCH FOR MAINTENANCE.
5. EXACT STRUCTURE TYPE, SIZE, LOCATION, AND WALLS TO BE DETERMINED.



PRELIMINARY - NOT FOR CONSTRUCTION

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DESIGNED BY	K. LAFORGE
ENTERED BY	M. KEILBART
CHECKED BY	J. HEILMAN
PROJ. ENGR.	J. METTLER
REGIONAL ADM.	

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER XXXXX

CONTRACT NO. | LOCATION NO. XL_____

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

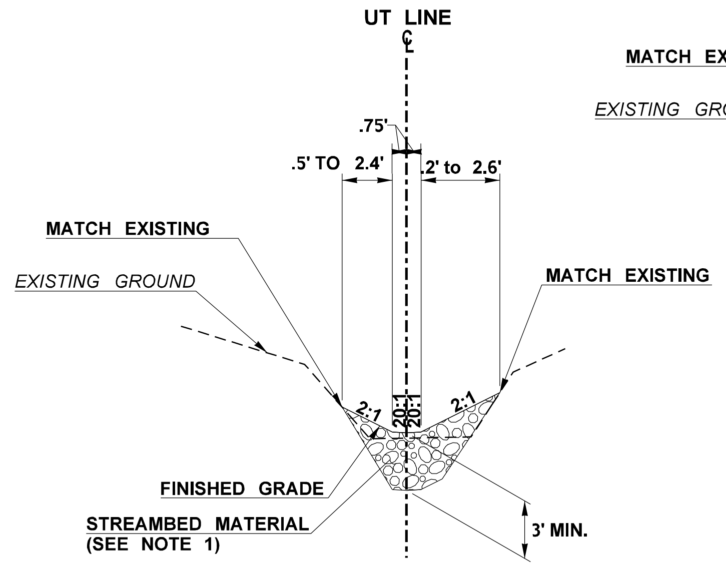
Washington State Department of Transportation

SR 3 MP 59.55
UNNAMED TO HOOD CANAL
FISH BARRIER REMOVAL

STREAM PROFILE

PLAN REF. NO. CP2

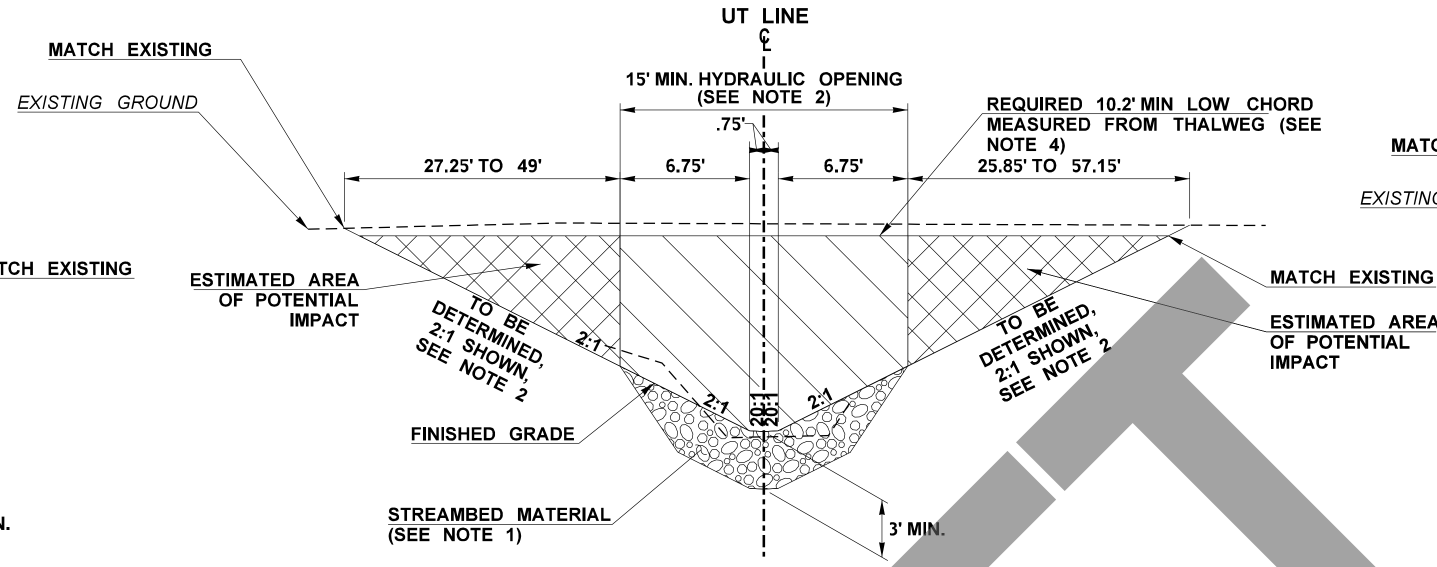
SHEET 3 OF 4 SHEETS



SECTION A

STATION
UT 2+93.69 TO 2+98.00

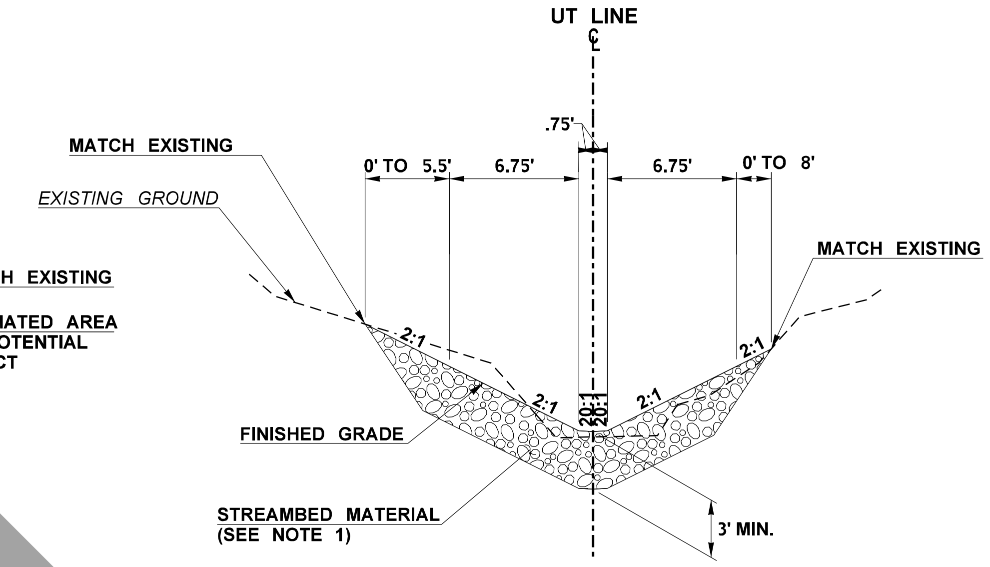
(SEE NOTE 5)



SECTION B

STATION
UT 3+11 TO 4+08

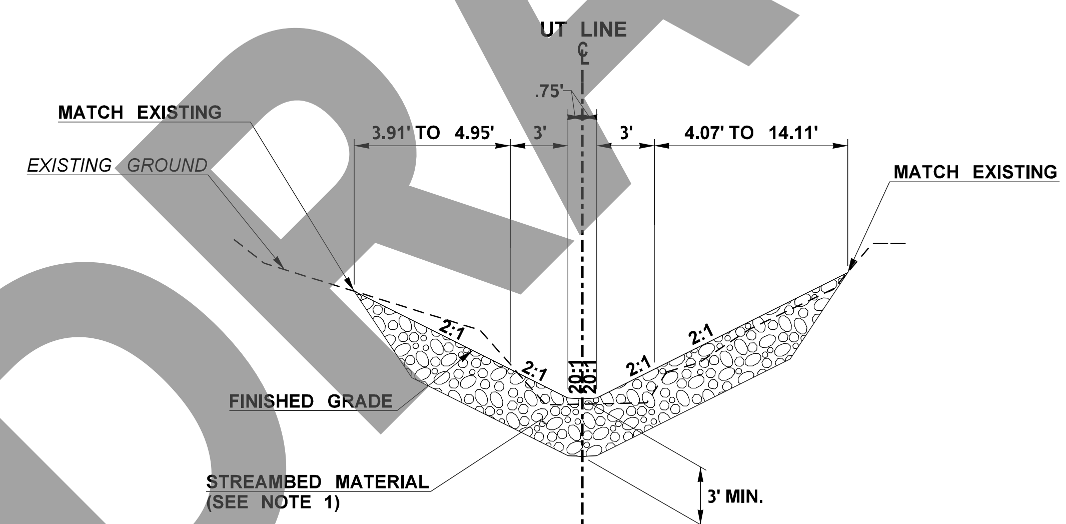
(SEE NOTES 3 & 4)



SECTION B

STATION
UT 2+98 TO 3+11
UT 4+08 TO 4+26

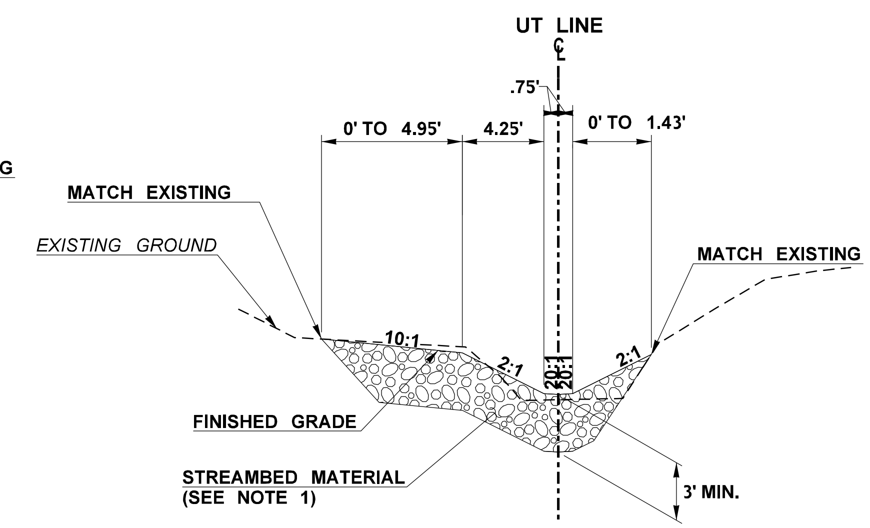
(SEE NOTES 3 & 4)



SECTION C

STATION
UT 4+26.00 TO 4+32.00

(SEE NOTE 3)



SECTION D

STATION
UT 4+32.00 TO 4+39.77

(SEE NOTE 6)

NOTES:

1. SEE SPECIAL PROVISIONS "AGGREGATE FOR STREAMS, RIVERS, AND WATERBODIES" FOR STREAMBED MATERIAL AND MATERIAL LIFTS. MATERIAL DEPTH IS APPROXIMATE. FINAL DEPTH TO BE DETERMINED FOLLOWING SCOUR ANALYSIS.
2. SLOPES SHOWN OUTSIDE OF THE MINIMUM CHANNEL SECTION ARE FOR ILLUSTRATIVE PURPOSES ONLY TO DEPICT ESTIMATED AREA OF POTENTIAL IMPACT. FINAL AREAS OF IMPACT TO BE DETERMINED PENDING GEOLOGICAL AND STRUCTURAL INVESTIGATION, STRUCTURE TYPE, AND STRUCTURE LOCATION.
3. PROPOSED STRUCTURE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY. STRUCTURE TYPE, SIZE, AND LOCATION TO BE DETERMINED DURING LATER PHASE OF DESIGN. PROPOSED STRUCTURE SHALL NOT ENCROACH INTO MINIMUM OPENING ON PLAN.
4. SEE SHEET CP1 FOR MINIMUM LOW CHORD ELEVATION THROUGHT STRUCTURE.
5. FROM UT 2+78.00 TO UT 2+93, EVENLY TAPER SECTION A TO MATCH EXISTING CHANNEL.
6. FROM UT 4+39 TO UT 4+54 EVENLY TAPER SECTION D TO MATCH EXISTING CHANNEL.

PRELIMINARY - NOT FOR CONSTRUCTION

pw:\\HQOLYMAPPPW03P.WSDOT.LOC:WSDOT\Documents_HQ\Fish Passage\ORproj\000\Y12554\Task Order AC\700PROJTEC\2_PHD_Working\SR003_MP59-55_UnnamedtoHoodCanal_996811_CAD_Sheets\XL_xxxx_DE_CD_001.dgn

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PLOTTED BY	Mike Keilbart			
DESIGNED BY	K. LAFORGE			
ENTERED BY	M. KEILBART			
CHECKED BY	J. HEILMAN			
PROJ. ENGR.	J. METTLER			
REGIONAL ADM.		REVISION	DATE	BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XXXXX		
CONTRACT NO.		LOCATION NO. XL_____

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State
Department of Transportation

SR 3 MP 59.55
UNNAMED TO HOOD CANAL
FISH BARRIER REMOVAL

STREAM DETAILS

PLAN REF NO CD1

SHEET 4 OF 4 SHEETS

Appendix E: Manning's Calculations

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name:	UNT to Hood Canal MP 59.55	**Reach:**	Channel
Stream Slope, *S* (ft/ft):	0.08000	**Date:**	6/7/2022
		Practitioner:	KML
Reach D_{50}, D_{84} (mm):		**Step D_{84} (mm)[(a)]:**	
Hydraulic Radius, *R* (ft):			
Mean Flow Depth, *d* (ft)[(b)]:			
Bedform Variation, σ_z (ft)[(c)]:			
Median Thalweg Depth, h_m (ft)[(c)]:			
Large Wood in Steps? (y/n)[(c)]:			

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 ft/ft (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:		----	
Estimate from Photographic Guidance:		----	

Instructions: **(See technical summary report, TS-103, for more detailed instructions and references.)**

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: UNT to Hood Canal MP 59.55
Slope, *S* (ft/ft): 0.08000
Reach: Channel
Date: 6/7/2022
Practitioner: KML

D_{50}, D_{84}, $D_{84,\,step}$ (m):	----	----	----
R (ft, m):	----	----	
d (ft^2, m^2):	----	----	
σ_z (ft, m):	----	----	
h_m (ft, m):	----	----	

Overall Average *n*:	----
***f*:**	----
Quantitative Average *n* (1):	----
***f* (1):**	----
Arcement and Schneider (1989) *n*:	0.165
***f*:**	----

3 Quantitative Prediction

Quasi-Quantitative:

	n_b (2)	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
Arcement and Schneider (1989) $n = (n_b + n_1 + n_2 + n_3 + n_4)m$	0.03	0.005		0.03	0.1	1	0.165	
	Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergenc	Estimate *n*	Estimate *f*	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub. (3)	Use in Average ? Enter
Yochum et al. (2012) [R^2 = 0.78; *f*: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	----	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002) (4) [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	----	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	----	----	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	----	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	----	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	----	----	----	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be appropraite to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or *d* and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name:	UNT to Hood Canal MP 59.55	**Reach:**	Floodplain
Stream Slope, *S* (ft/ft):	0.08000	**Date:**	6/7/2022
		Practitioner:	KML

Reach D_{50}, D_{84} (mm):		**Step D_{84} (mm)[a]:**	
Hydraulic Radius, *R* (ft):			
Mean Flow Depth, *d* (ft)[b]:			
Bedform Variation, σ_z (ft)[c]:			
Median Thalweg Depth, h_m (ft)[c]:			
Large Wood in Steps? (y/n)[c]:			

Notes:
(a) Required for Lee and Ferguson (2002) method, for step-pool streams (S>0.027)
(b) Mean flow depth = hydraulic depth; Required for Bathurst (1985), Rickenmann and Recking (2011), and Aberle and Smart (2003) methods
(c) Longitudinally; Provide for S>~0.03 ft/ft (see sheet "S>0.03, Sigma z")

1 **Consult Tabular Guidance** → 2 **Consult Photographic** → 3 **Apply a Quantitative Prediction Method**

Flow resistance in stream channels is due to roughness induced by bed and bank grain material, bedforms (such as dunes and step pools), planform, vegetation, large instream wood, and other obstructions. Flow resistance coefficient estimation (Manning's *n* , Darcy-Weisbach *f*) is approximate, requiring redundancy (steps 1 through 3) for confidence in the implimented values. Dependence on quantitative methods alone is not recommended since utilized reaches in the derivisions were intentionally selected to have little influence from sinuosity, instream large wood, streambank vegetation, bank irregularities, obstructions, etc.; these types of flow resistance are not lumped into the quantitative estimates. Also, flow resistance coefficients should be computed at the flow magnitude of interest for the objectives of the analysis, specifically at high, bankfull, or low flow.

1 Tabular Guidance

Sources: Brunner (2016): pp 3-14
Arcement and Schneider (1989): p 4
Aldridge and Garrett (1973): p 24

Note: Key references are provided in the spreadsheet package zip file or are available for download through the links provided in the references of the supporting technical summary report (TS-103).

2 Photographic Guidance

Sources: USGS (online photo guidance)
Yochum et al. (2014): high gradient
Hicks and Mason (1991)
Aldridge and Garrett (1973)
Barnes (1967)

	n	*f*	Use in Average? Enter "y"
Tabular Estimate:		----	
Estimate from Photographic Guidance:		----	

Instructions: (See technical summary report, TS-103, for more detailed instructions and references.)

(1) Grey cells indicate fields that should be populated. Results are provided in the salmon colored cells.
(2) Enter background information (cells D4, D5, I4 to I6), sediment size data (cells D8, E8, H8), and hydraulic information (cells D9 to D13). R is often approximated as the average depth for steams with a width/depth ratio > ~20.
(3) Consult tabular guidance and enter the best estimate in the grey box (cell I43; do not use in average if not confident of estimate). Tabular values are typically substantially underestimated for channels > ~3% slope.
(4) Consult photographic guidance and enter an estimate in the grey box (cell I44).
(5) Applicable quantitative procedures will be automatically compute (per provided Applicable Range).
(6) Implement Arcement and Schneider (1989) procedure, if desired (cells T20 to Y20).

U.S. Forest Service
National Stream and Aquatic Ecology Center
Tool developed by: Steven E. Yochum, PhD, PE, Hydrologist
Tool reviewed by: Julian A. Scott, Hydrolgist

Stream Channel Flow Resistance Coefficient Computation Tool (version 1.1, 2-2018)

Stream Name: UNT to Hood Canal MP 59.55 **Reach:** Floodplain
Slope, *S* (ft/ft): 0.08000 **Date:** 6/7/2022
Practitioner: KML

D_{50}, D_{84}, $D_{84,\ step}$ (m):	----	----	----
R (ft, m):	----	----	
d (ft^2, m^2):	----	----	
σ_z (ft, m):	----	----	
h_m (ft, m):	----	----	

Overall Average *n*:	----
***f*:**	----
Quantitative Average *n* (1):	----
***f* (1):**	----
Arcement and Schneider (1989) *n*:	0.108
***f*:**	----

3 Quantitative Prediction

Quasi-Quantitative:

Arcement and Schneider (1989)

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m$$

n_b (2)	n_1	n_2	n_3	n_4	m	Estimate	Use in Average? Enter "y"
0.03	0.01	0.01	0.02	0.02	1.2	0.108	
Base	Degree of Irrigularity	Variation in X-S	Effect of Obstruction	Amount of Vegetation	Degree of Meandering		

Fully Quantitative:

Method [Fit]	Relative Submergenc	Estimate *n*	Estimate *f*	# Data Points	Applicable Range Slope (ft/ft)	Applicable Range Relative Sub.(3)	Use in Average ? Enter
Yochum et al. (2012) [R^2 = 0.78; *f*: R^2 = 0.82]	----	----	----	78	0.02 to 0.20	h_m/σ_z = 0.25 to 12	
Rickenmann and Recking (2011)	----	----	----	2890	0.00004 to 0.03	d/D_{84} = 0.18 to ~100	
Aberle and Smart (2003); in flume	----	----	----	94	0.02 to 0.10	d/σ_z = 1.2 to 12	
Lee and Ferguson (2002)(4) [RMS error = 19%]	----	----	----	81	0.027 to 0.184	R/D_{84} (step) = 0.1 to 1.4	
Bathurst (1985) [RMS error = ~34%]	----	----	----	44	0.00429 to 0.0373	d/D_{84} = 0.71 to 11.4	
Jarrett (1984) [ave. std. error = 28%]	n/a	----	----	75	0.002 to 0.039	n/a	
Griffiths (1981); rigid bed [R^2=0.59]	----	----	----	84	0.000085 to 0.011	R/D_{50} = 1.8 to 181	
Hey (1979); a = 12.72	----	----	----	30	0.00049 to ~0.01	R/D_{84} = 0.8 to 25	
Limerinos (1970) [R^2=0.77]	----	----	----	50	0.00038 to 0.039	R/D_{84} = 1.1 to 69	

Notes:
(1) Quantitative average excludes the Arcement and Schneider (1989) method.
(2) In some situations it can be appropraite to assume that the quantitative average n is n_b., though this may result in overestimated flow resistance.
(3) Relative submergence is computed using either *R* (hydraulic radius) or d (mean depth) and the D_{50} (median bed material size) or D_{84} (84% of bed material smaller); or computed using either h_m (median thalweg depth) or d and σ_z (standard deviation of residuals of a thalweg longitudinal profile regression). For σ_z computation, see "S>0.03, Sigma z" tab of this spreadsheet.
(4) This method can substantially underestimate flow resistance in steeper streams (slope>0.03) where large wood is

This spreadsheet has been reviewed for accuracy. However, the ultimate responsibility for flow resistance estimates remains with the user.
U.S. Forest Service
National Stream and Aquatic Ecology Center

Appendix F: Large Woody Material Calculations

BURIED STRUCTURE

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*SR 3 MP 59.55*		Key piece volume	*1.310*	*yd^3*
Stream name	*UNT to Hood Canal*		Key piece/ft	*0.0335*	*per ft stream*
length of regrade[a]	*146*	*ft*	Total wood vol./ft	*0.3948*	*yd^3/ft stream*
Bankfull width	*6*	*ft*	Total LWM[c] pieces/ft stream	*0.1159*	*per ft stream*
Habitat zone[b]	*Western WA*				

Taper coeff.	-0.01554
LF_{rw}	1.5
H_{dbh}	4.5

Log type	*Diameter at midpoint (ft)*	*Length(ft)[d]*	*Volume (yd^3/log)[d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*	DBH based on mid point diameter	$D_{root\ collar}$ (ft)	L/2-Lrw (ft)
A	1.75	*15*	1.34	yes	yes	5	6.68	1.76	1.83	4.875
B	1.00	*15*	0.44	yes	no	9	3.93	1.02	1.09	6
C	0.67	*10*	0.13	yes	no	5	0.65	0.66	0.73	3.995
D			0.00	yes			0.00		0.00	0
E			0.00				0.00		0.00	0
F			0.00				0.00		0.00	0
G			0.00				0.00		0.00	0
H			0.00				0.00		0.00	0
I			0.00				0.00		0.00	0
J			0.00				0.00		0.00	0
K			0.00				0.00		0.00	0
L			0.00				0.00		0.00	0
M			0.00				0.00		0.00	0
N			0.00				0.00		0.00	0
O			0.00				0.00		0.00	0
P			0.00				0.00		0.00	0

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	5	19	11.3
Targets	5	17	57.6
	on target	surplus	deficit

[a] includes length through crossing, regardless of structure type

[b] choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information

Western Washington	(generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine	(generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa	(mainly east slope Cascades below 3,700 ft. elevation)

[c]LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).

[d]includes rootwad if present

BRIDGE STRUCTURE

WSDOT Large Woody Material for stream restoration metrics calculator

State Route# & MP	*SR 3 MP 59.55*		Key piece volume	*1.310*	*yd^3*		
Stream name	*UNT to Hood Canal*		Key piece/ft	*0.0335*	*per ft stream*		
length of regrade[a]	*146*	*ft*	Total wood vol./ft	*0.3948*	*yd^3/ft stream*	Taper coeff.	-0.01554
Bankfull width	*6*	*ft*	Total LWM[c] pieces/ft stream	*0.1159*	*per ft stream*	LF_{rw}	1.5
Habitat zone[b]	*Western WA*					H_{dbh}	4.5

Log type	*Diameter at midpoint (ft)*	*Length(ft)[d]*	*Volume (yd^3/log)[d]*	*Rootwad?*	*Qualifies as key piece?*	*No. LWM pieces*	*Total wood volume (yd^3)*	DBH based on mid point diameter	$D_{root\ collar}$ (ft)	L/2-Lrw (ft)
A	1.75	15	1.34	yes	yes	5	6.68	1.76	1.83	4.875
B	1.00	15	0.44	yes	no	14	6.11	1.02	1.09	6
C	0.67	10	0.13	yes	no	9	1.18	0.66	0.73	3.995
D			0.00	yes			0.00		0.00	0
E			0.00				0.00		0.00	0
F			0.00				0.00		0.00	0
G			0.00				0.00		0.00	0
H			0.00				0.00		0.00	0
I			0.00				0.00		0.00	0
J			0.00				0.00		0.00	0
K			0.00				0.00		0.00	0
L			0.00				0.00		0.00	0
M			0.00				0.00		0.00	0
N			0.00				0.00		0.00	0
O			0.00				0.00		0.00	0
P			0.00				0.00		0.00	0

	No. of key pieces	Total No. of LWM pieces	Total LWM volume (yd^3)
Design	5	28	14.0
Targets	5	17	57.6
	on target	surplus	deficit

[a] includes length through crossing, regardless of structure type

[b] choose one of the following Forest Regions in the drop-down menu (if in doubt ask HQ Biology). See also the Forest Region tab for additional information

Western Washington	(generally <4,200 ft. in elevation west of the Cascade Crest)
Alpine	(generally > 4,200 ft. in elevation and down to ~3,700 ft. in elevation east of the Cascade crest)
Douglas fir-Ponderosa	(mainly east slope Cascades below 3,700 ft. elevation)

[c] LWM (Large Woody Material), also known as LWD (Large Woody Debris) is defined as a piece of wood at least 10 cm (4") diam. X 2 m (6ft) long (Fox 2001).

[d] includes rootwad if present

Appendix G: Future Projections for Climate-Adapted Culvert Design

Future Projections for Climate-Adapted Culvert Design

Project Name:

Stream Name:

Drainage Area: 63 ac

Projected mean percent change in bankfull flow:

2040s: 12.4%

2080s: 14.5%

Projected mean percent change in bankfull width:

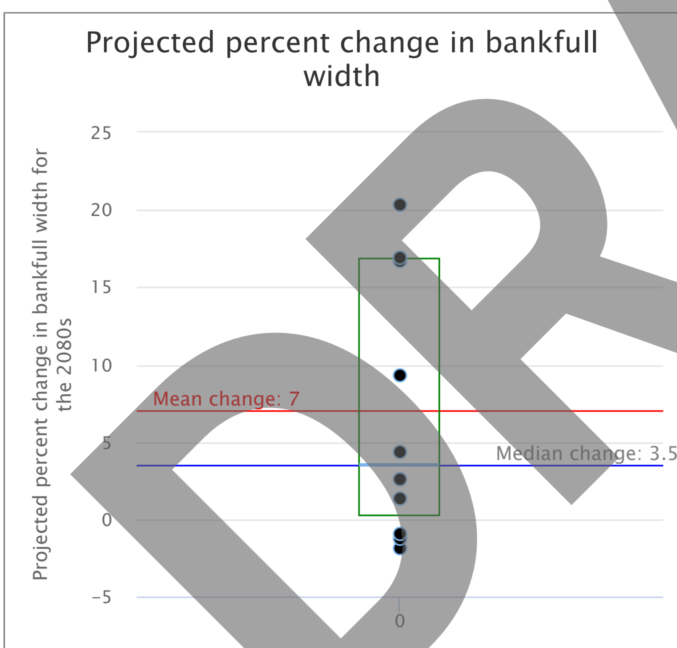
2040s: 6%

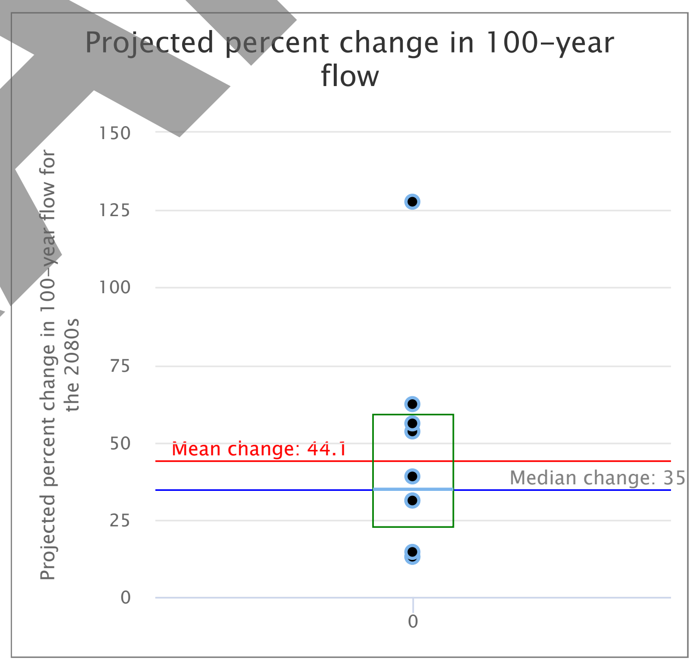
2080s: 7%

Projected mean percent change in 100-year flood:

2040s: 28.1%

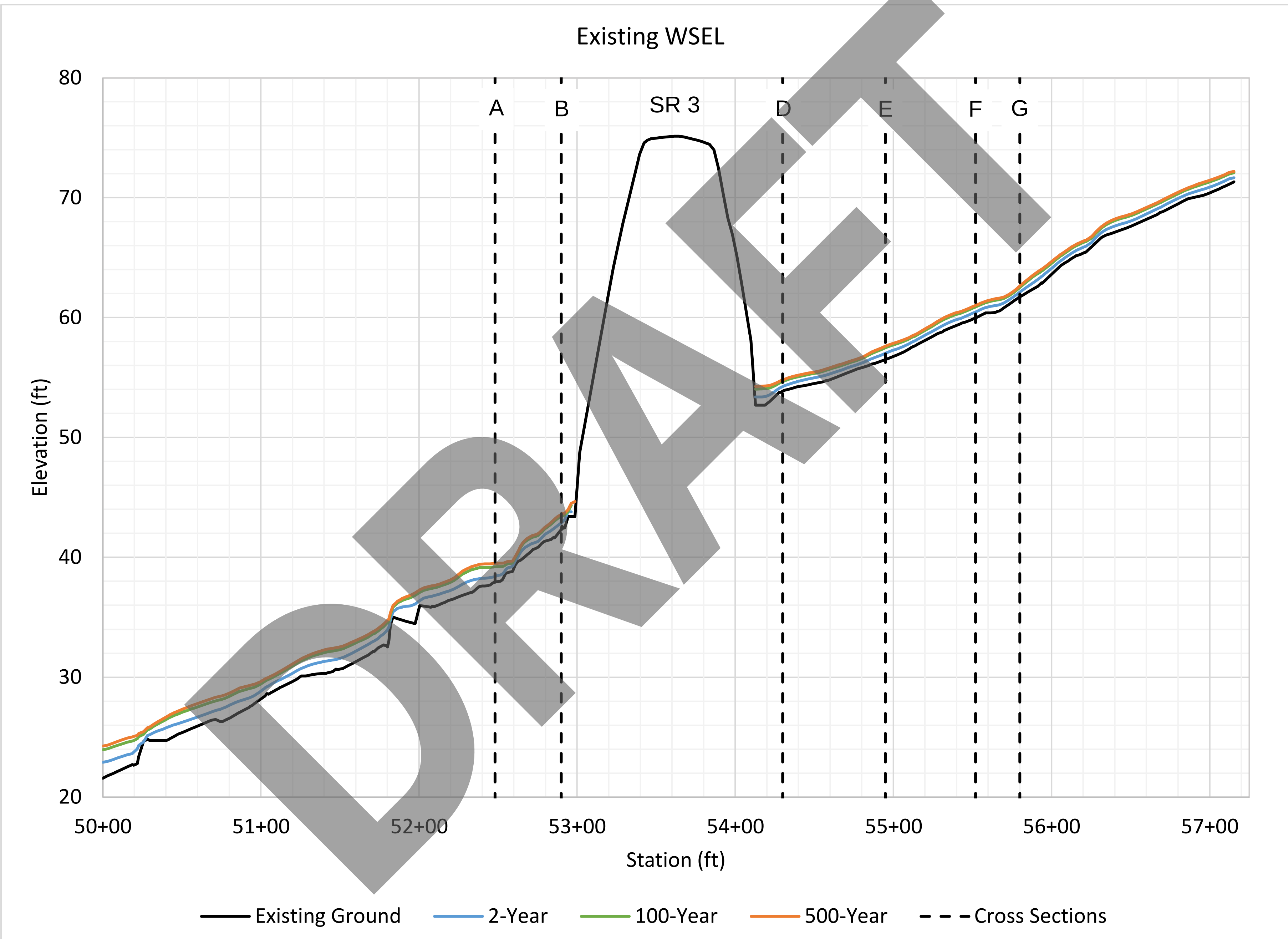
2080s: 44.1%



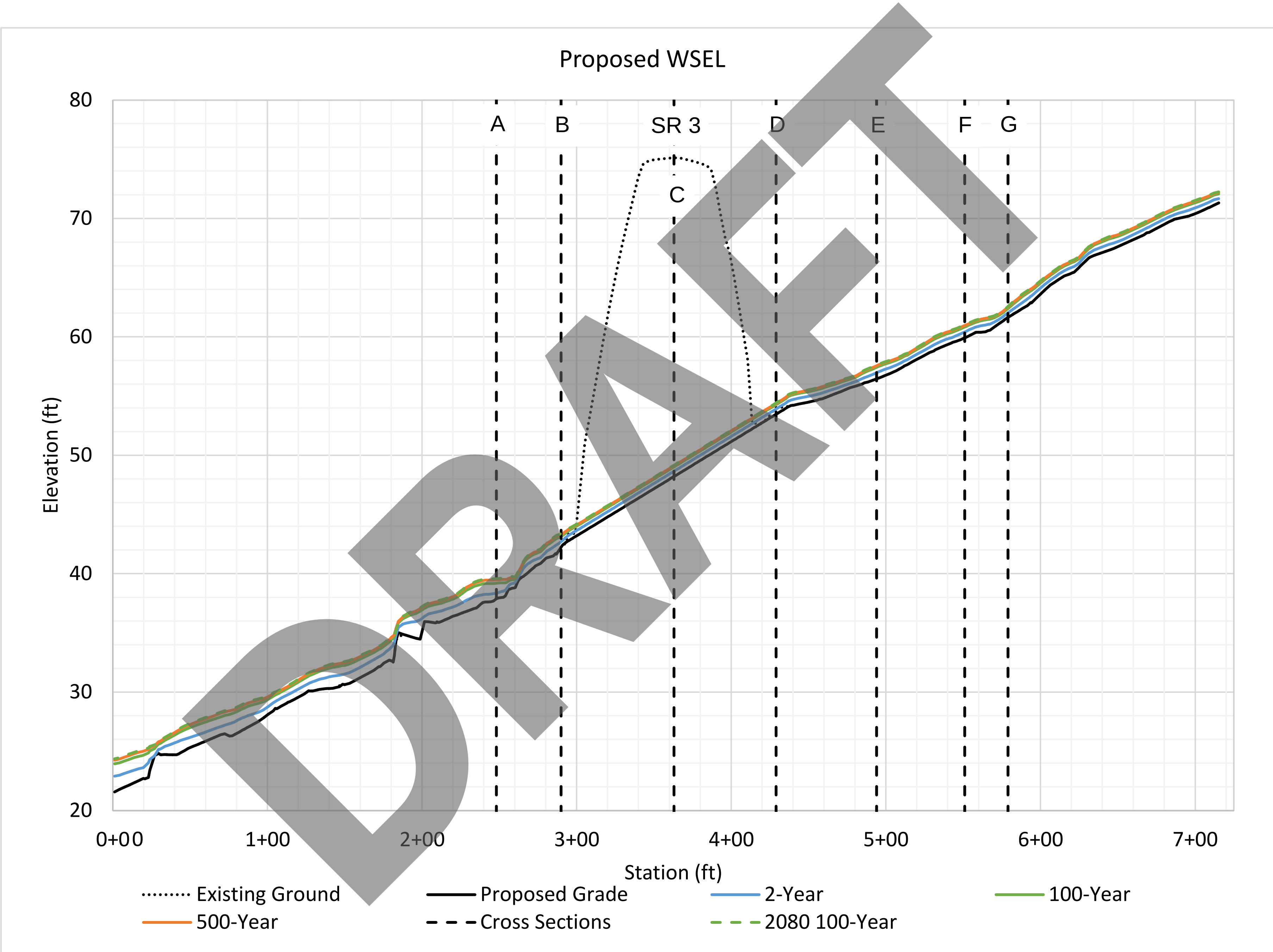


Black dots are projections from 10 separate models

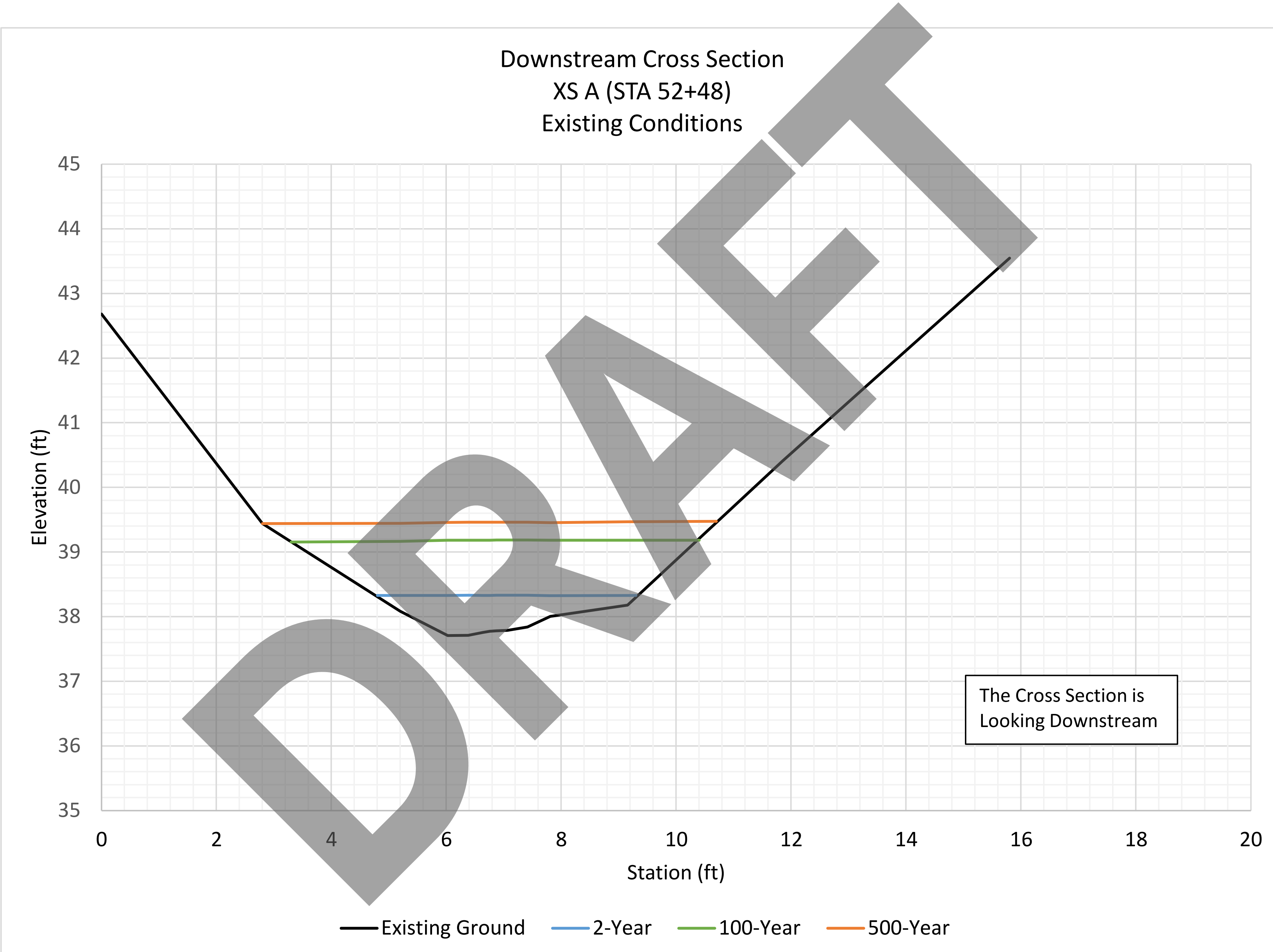
Appendix H: SRH-2D Model Results

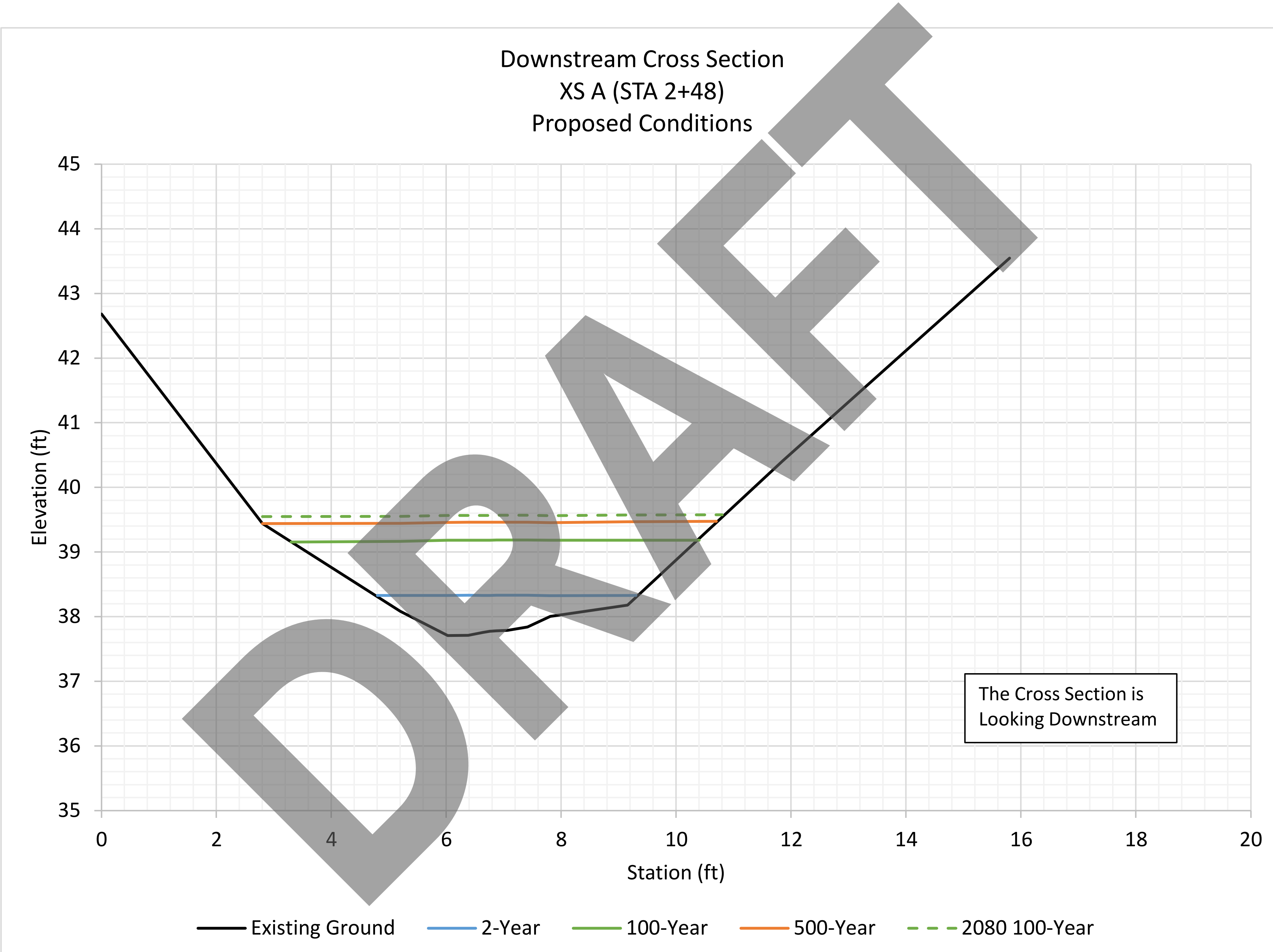


Existing WSEL
80
70
60
50
40
30
20
Elevation (ft)
A
B
SR 3
D
E
F
G
50+00
51+00
52+00
53+00
54+00
55+00
56+00
57+00
Station (ft)
Existing Ground
2-Year
100-Year
500-Year
Cross Sections
DRAFT

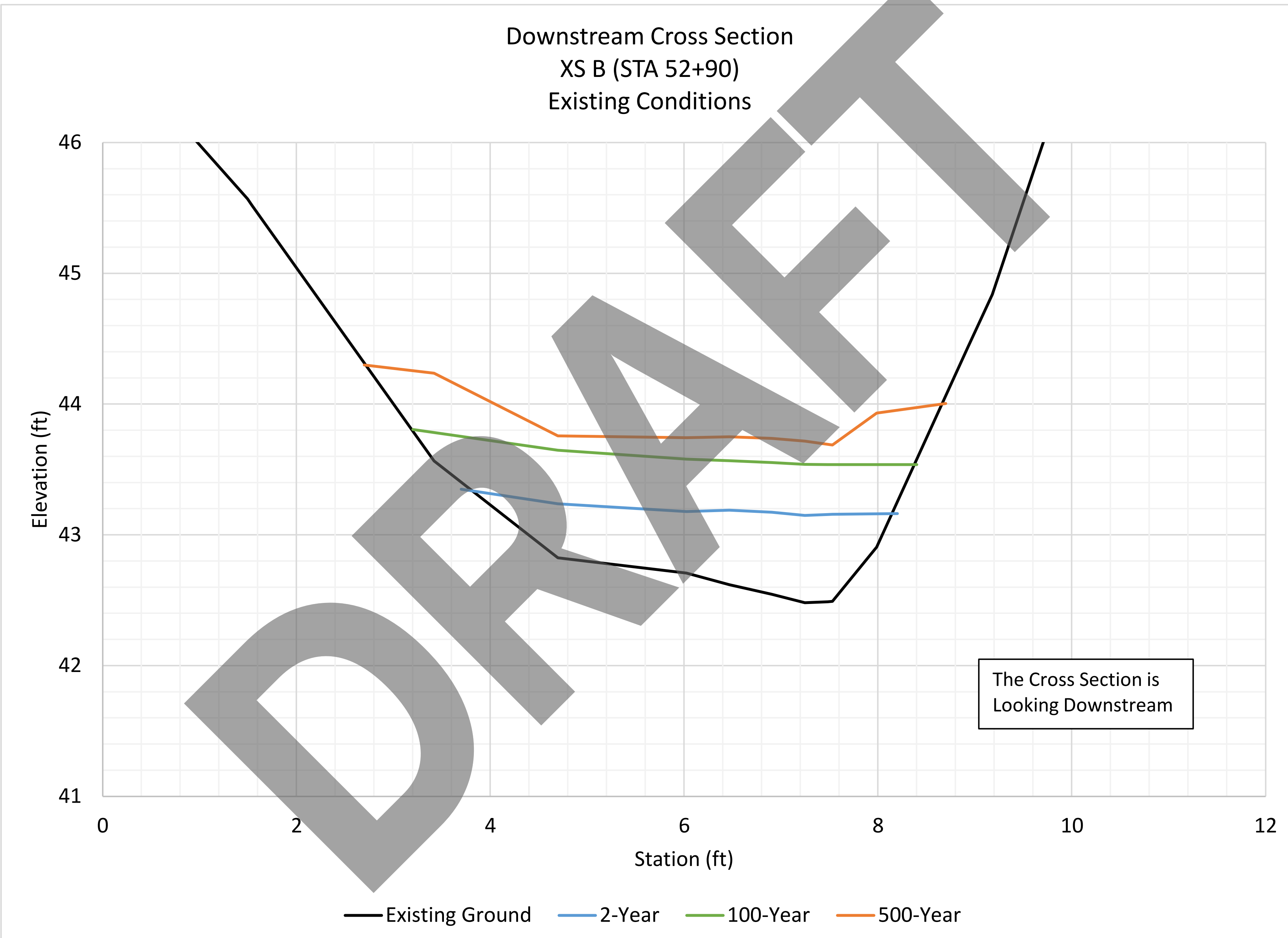


Proposed WSEL
80
70
60
50
40
30
20
Elevation (ft)
A
B
SR 3
C
D
E
F
G
0+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
Station (ft)
Existing Ground
Proposed Grade
2-Year
100-Year
500-Year
Cross Sections
2080 100-Year
DRAFT

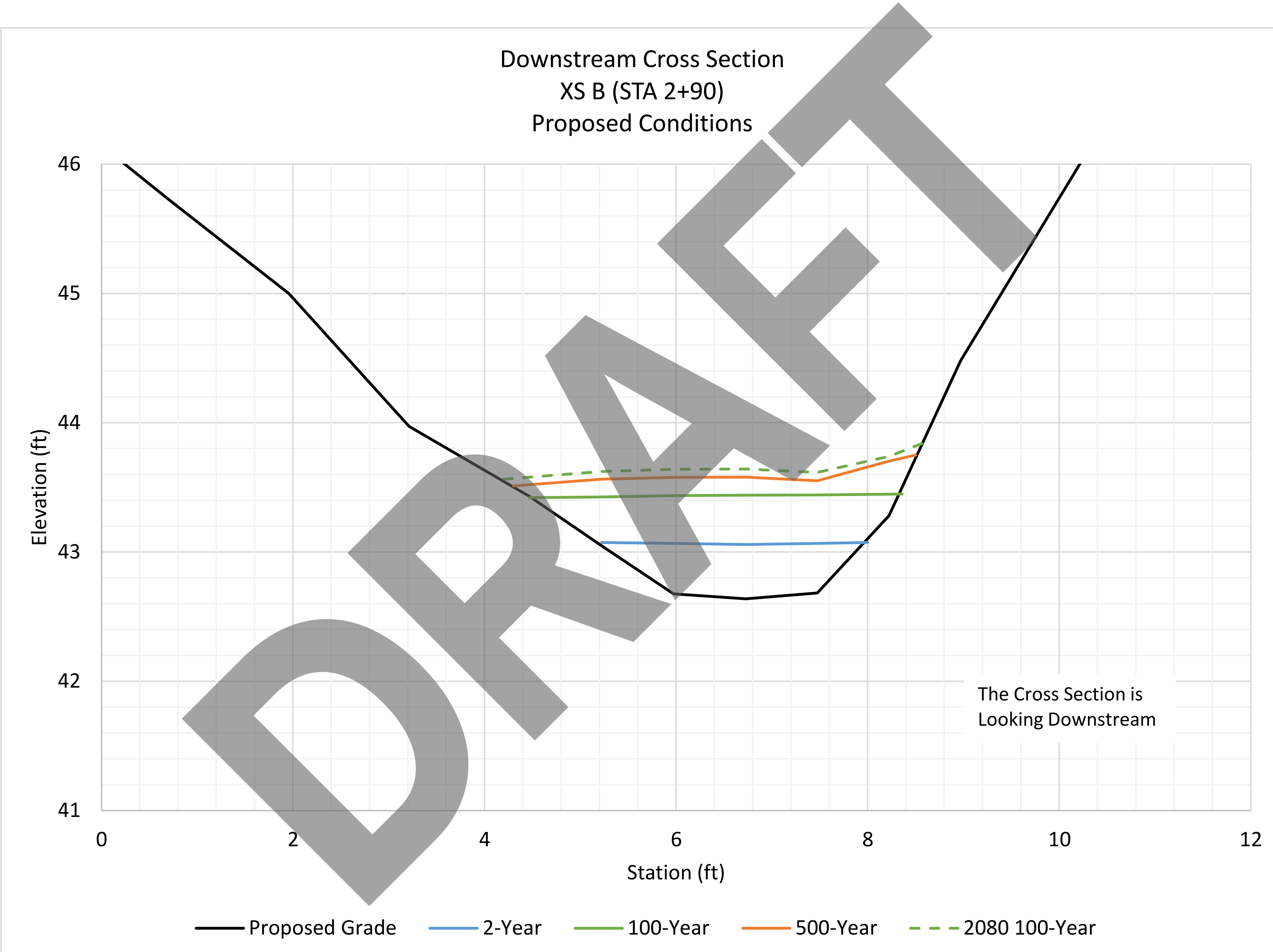

Downstream Cross Section
XS A (STA 52+48)
Existing Conditions
Elevation (ft)
45
44
43
42
41
40
39
38
37
36
35
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
DRAFT

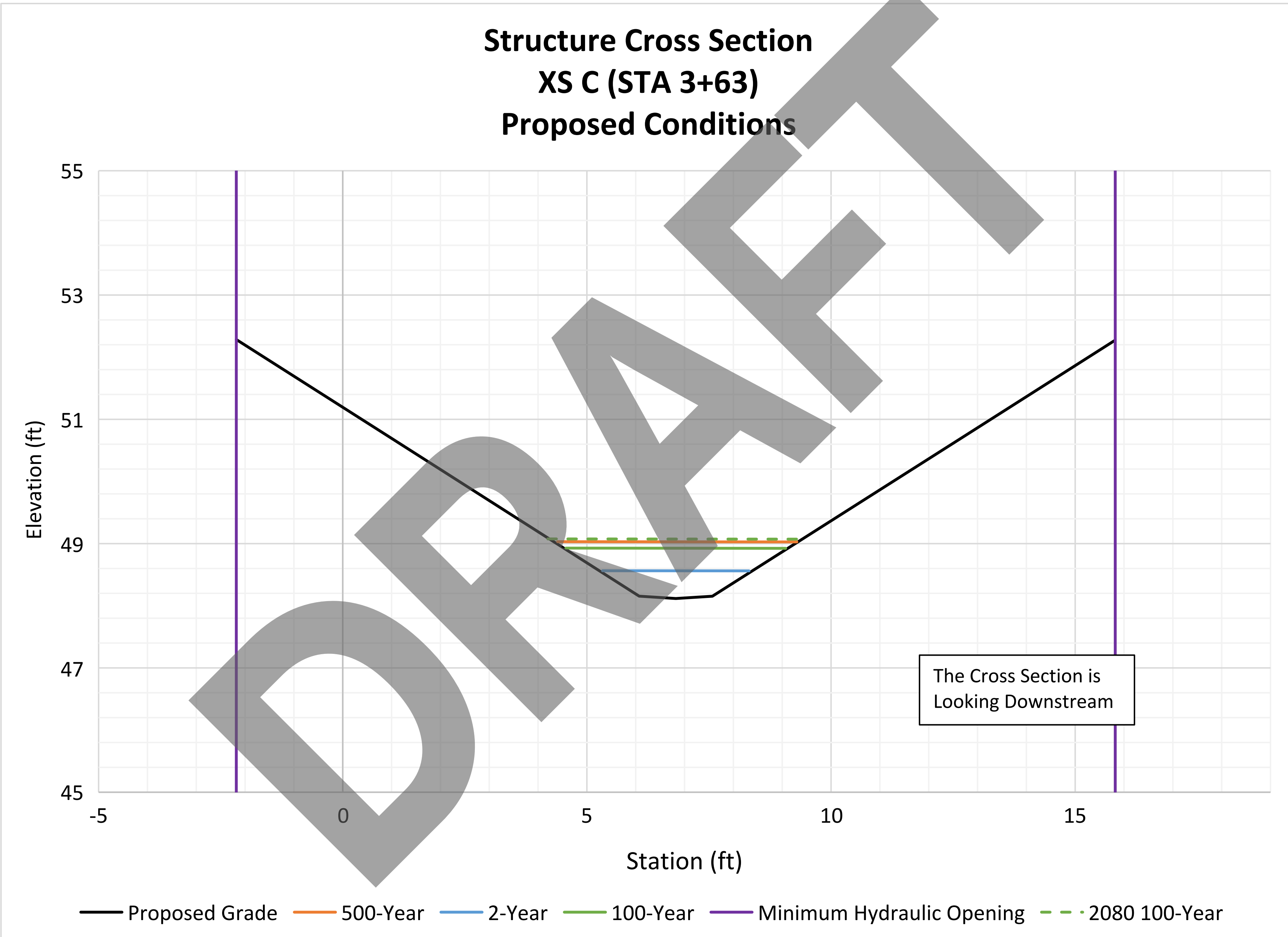


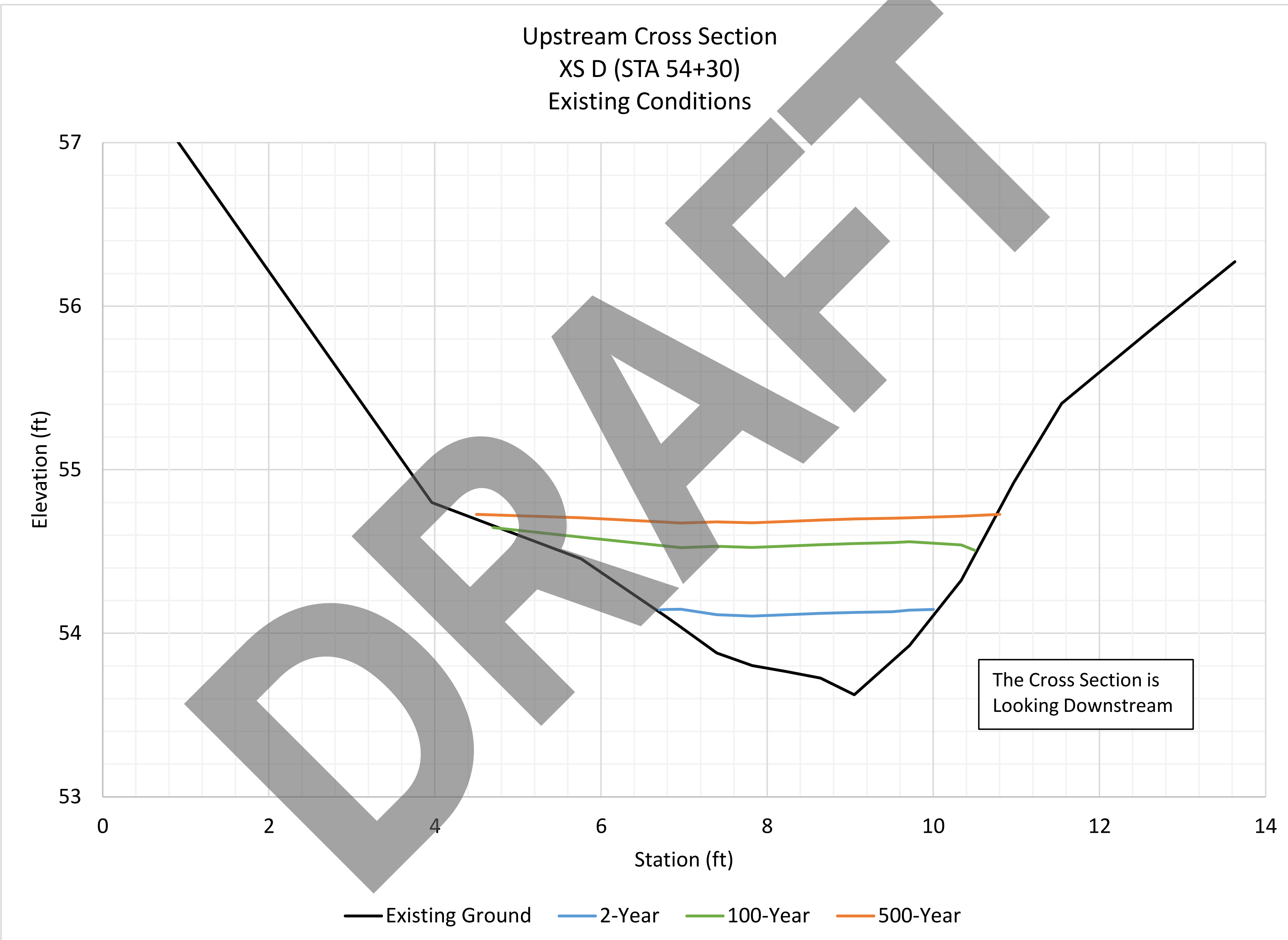
Downstream Cross Section
XS A (STA 2+48)
Proposed Conditions
Elevation (ft)
45
44
43
42
41
40
39
38
37
36
35
0
2
4
6
8
10
12
14
16
18
20
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
2080 100-Year
DRAFT

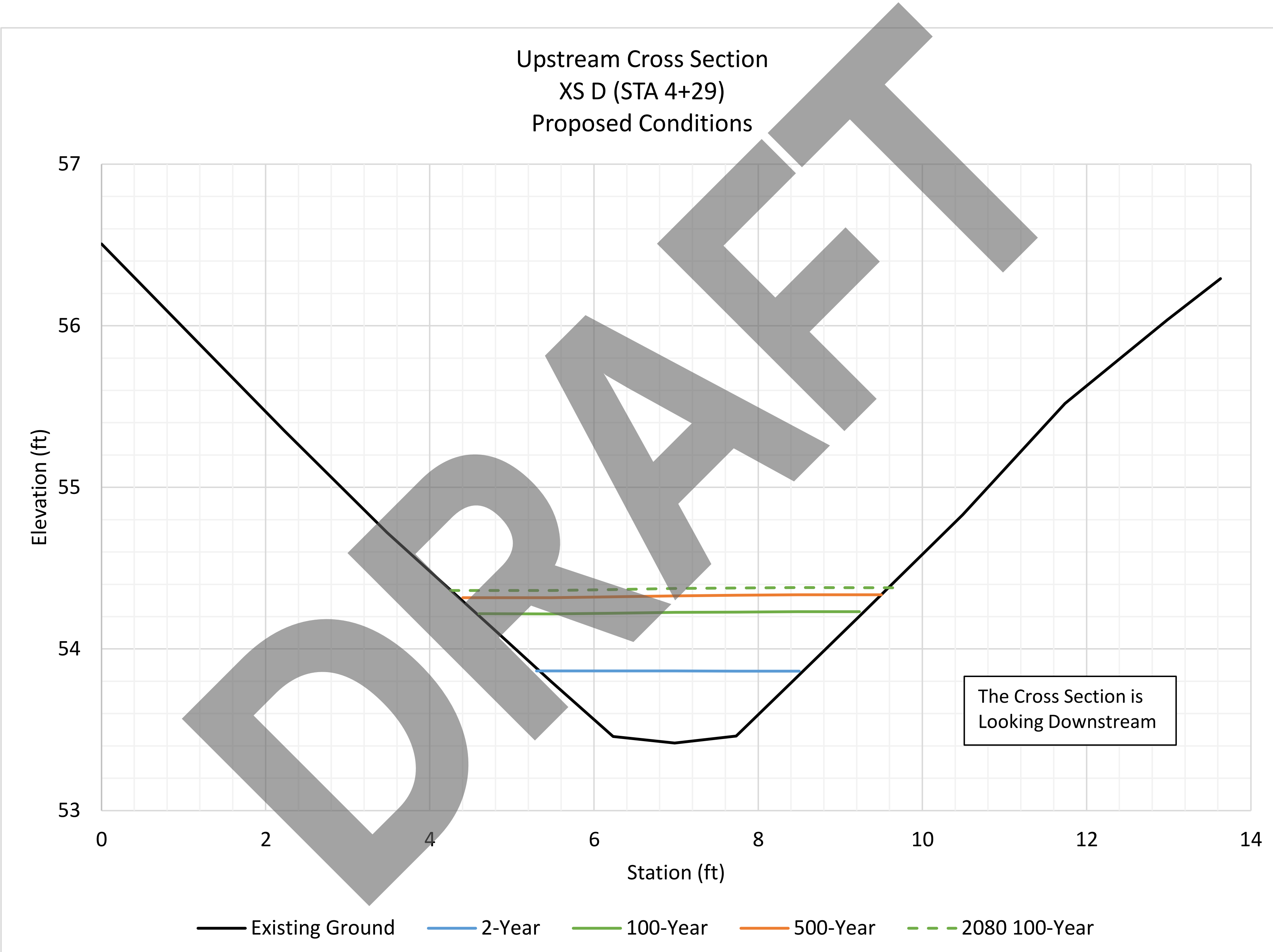


Downstream Cross Section
XS B (STA 52+90)
Existing Conditions
Elevation (ft)
46
45
44
43
42
41
0
2
4
6
8
10
12
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
DRAFT

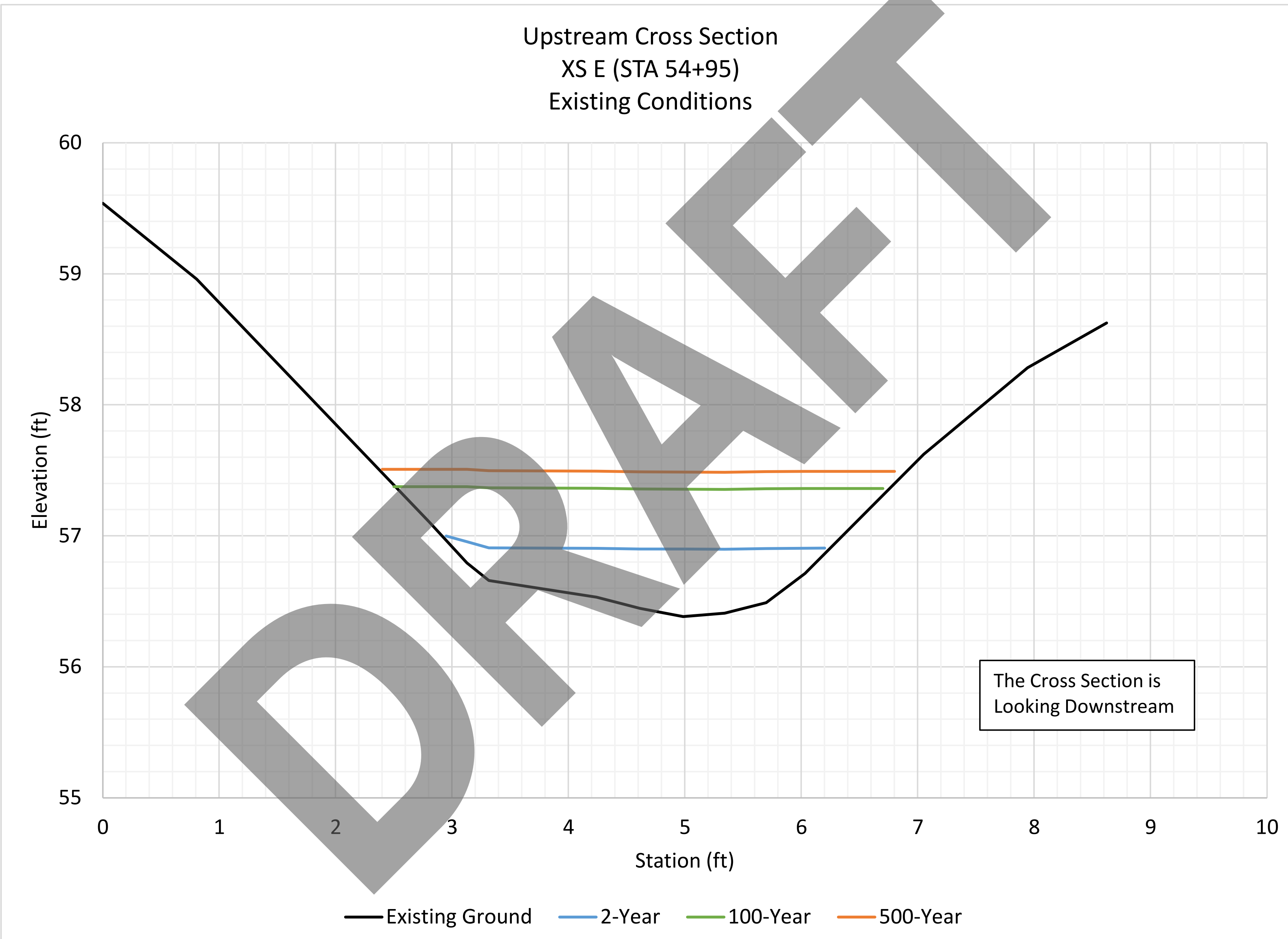

Downstream Cross Section
XS B (STA 2+90)
Proposed Conditions
Elevation (ft)
46
45
44
43
42
41
0
2
4
6
8
10
12
Station (ft)
The Cross Section is Looking Downstream
Proposed Grade
2-Year
100-Year
500-Year
2080 100-Year
DRAFT

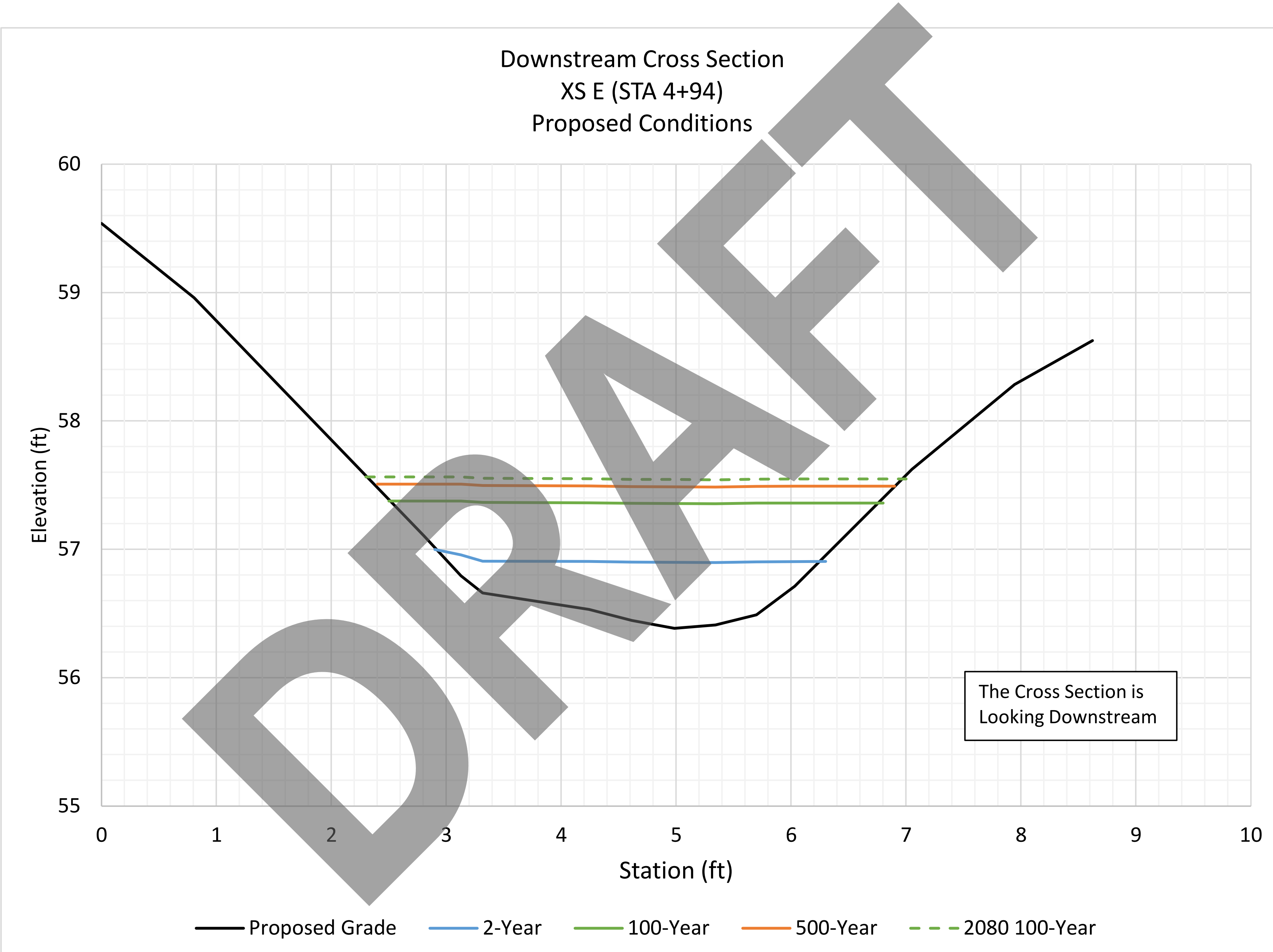

Structure Cross Section
XS C (STA 3+63)
Proposed Conditions
DRAFT
Elevation (ft)
55
53
51
49
47
45
-5
0
5
10
15
Station (ft)
The Cross Section is Looking Downstream
Proposed Grade
500-Year
2-Year
100-Year
Minimum Hydraulic Opening
2080 100-Year


Upstream Cross Section
XS D (STA 54+30)
Existing Conditions
57
56
55
54
53
Elevation (ft)
0
2
4
6
8
10
12
14
Station (ft)
The Cross Section is
Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
DRAFT

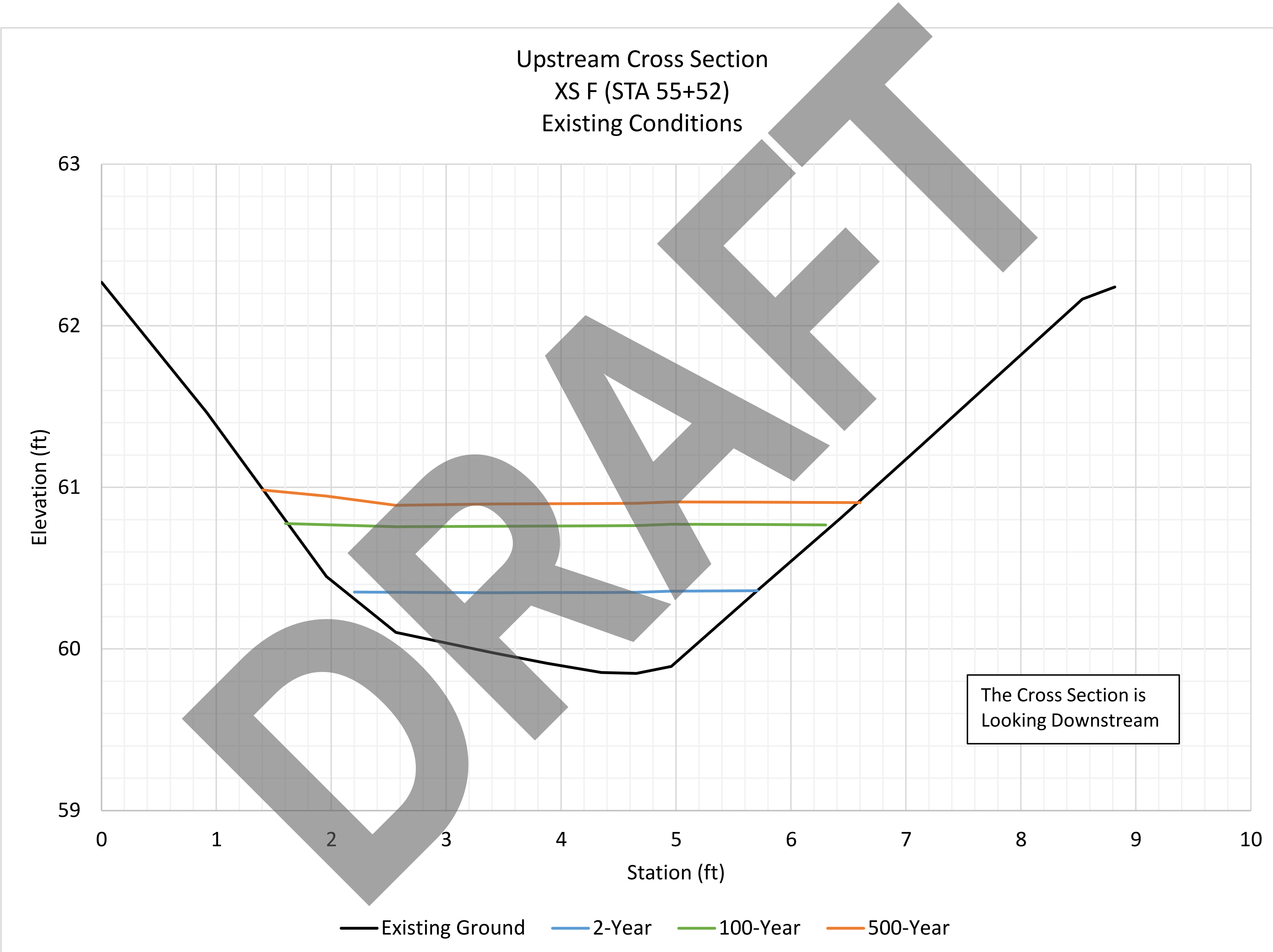


Upstream Cross Section
XS D (STA 4+29)
Proposed Conditions
57
56
55
54
53
Elevation (ft)
0
2
4
6
8
10
12
14
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
2080 100-Year
DRAFT

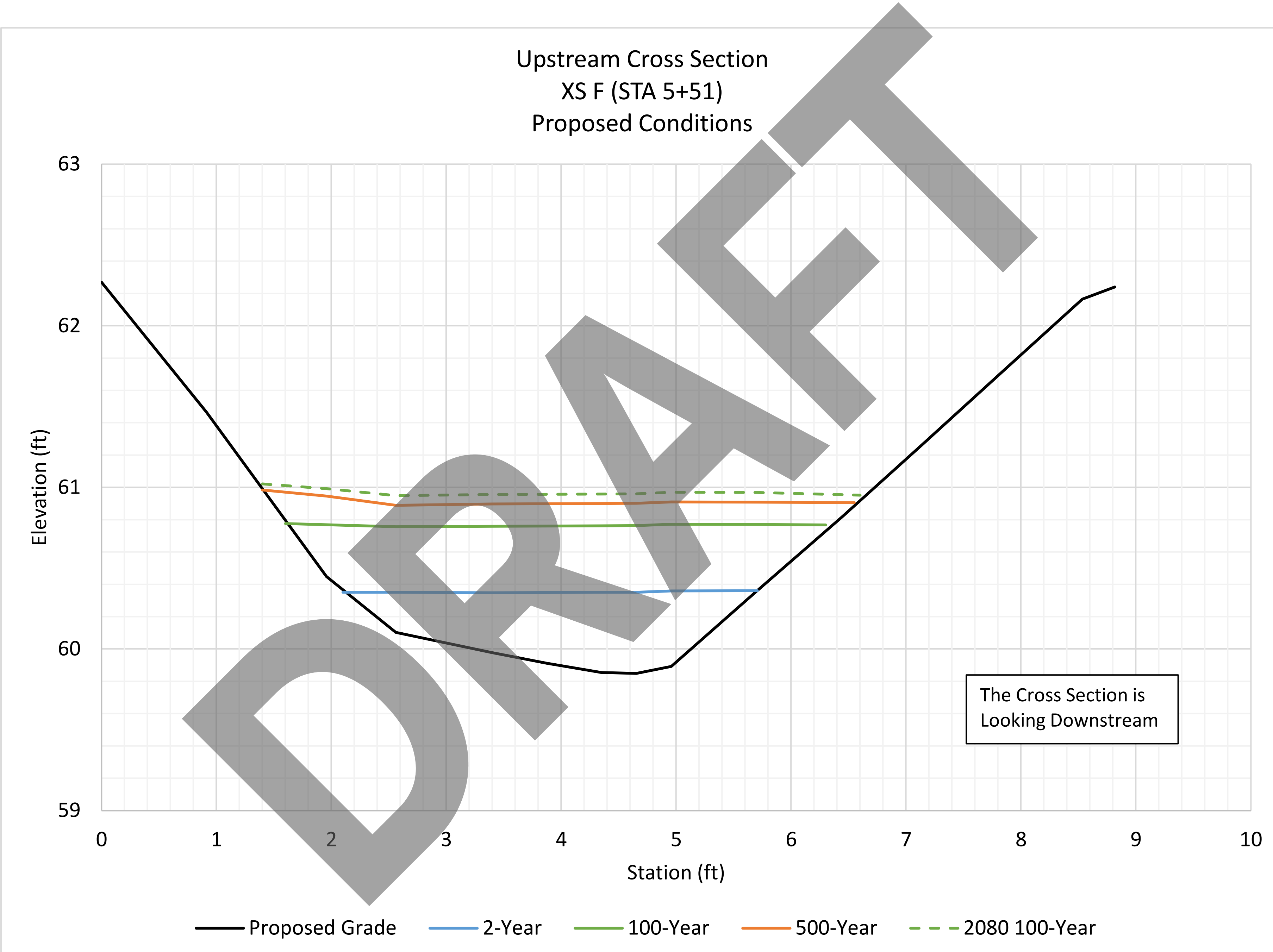

Upstream Cross Section
XS E (STA 54+95)
Existing Conditions
Elevation (ft)
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
DRAFT
60
59
58
57
56
55
0
1
2
3
4
5
6
7
8
9
10



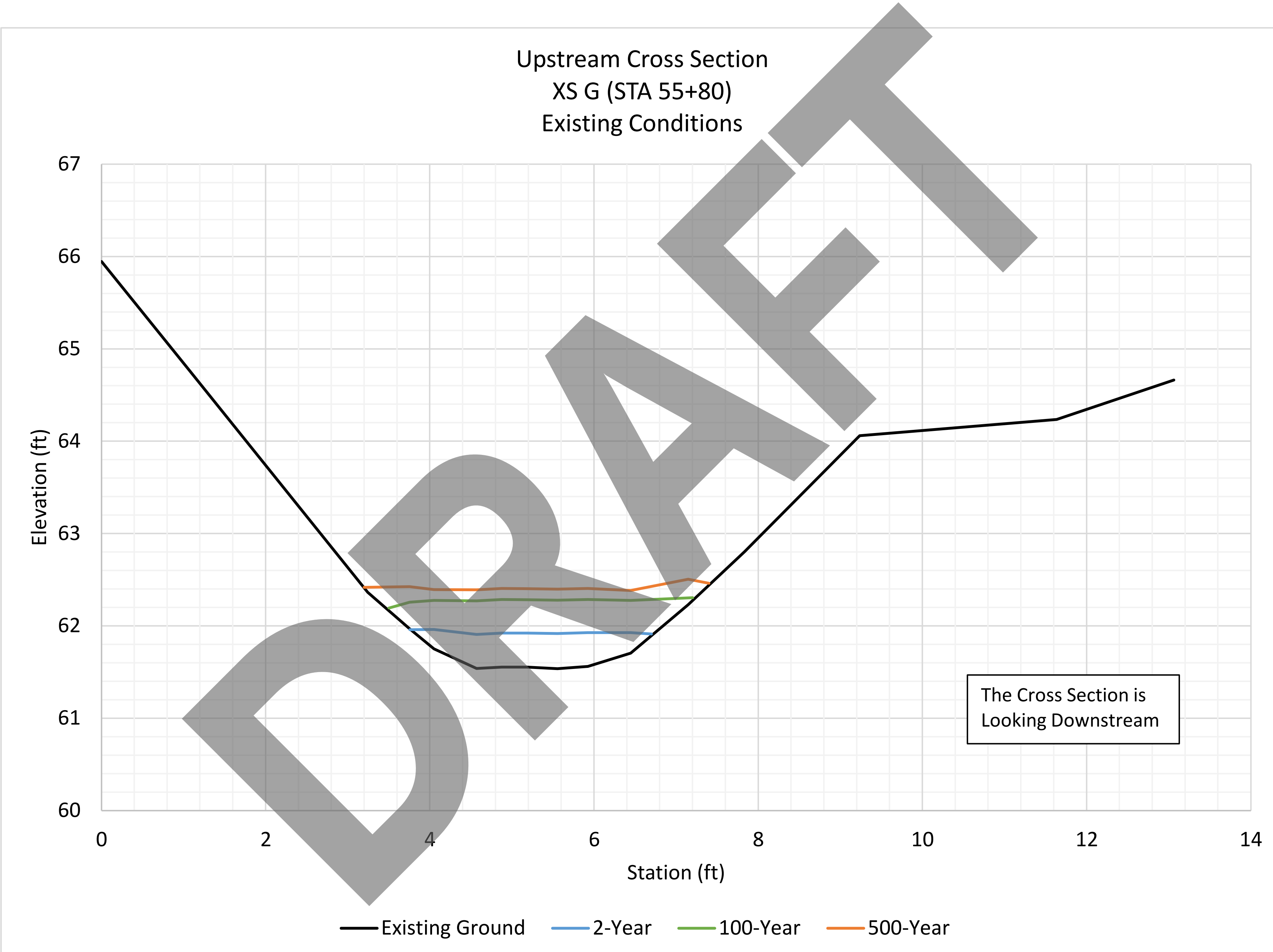
Downstream Cross Section
XS E (STA 4+94)
Proposed Conditions
Elevation (ft)
60
59
58
57
56
55
0
1
2
3
4
5
6
7
8
9
10
Station (ft)
The Cross Section is Looking Downstream
Proposed Grade
2-Year
100-Year
500-Year
2080 100-Year
DRAFT



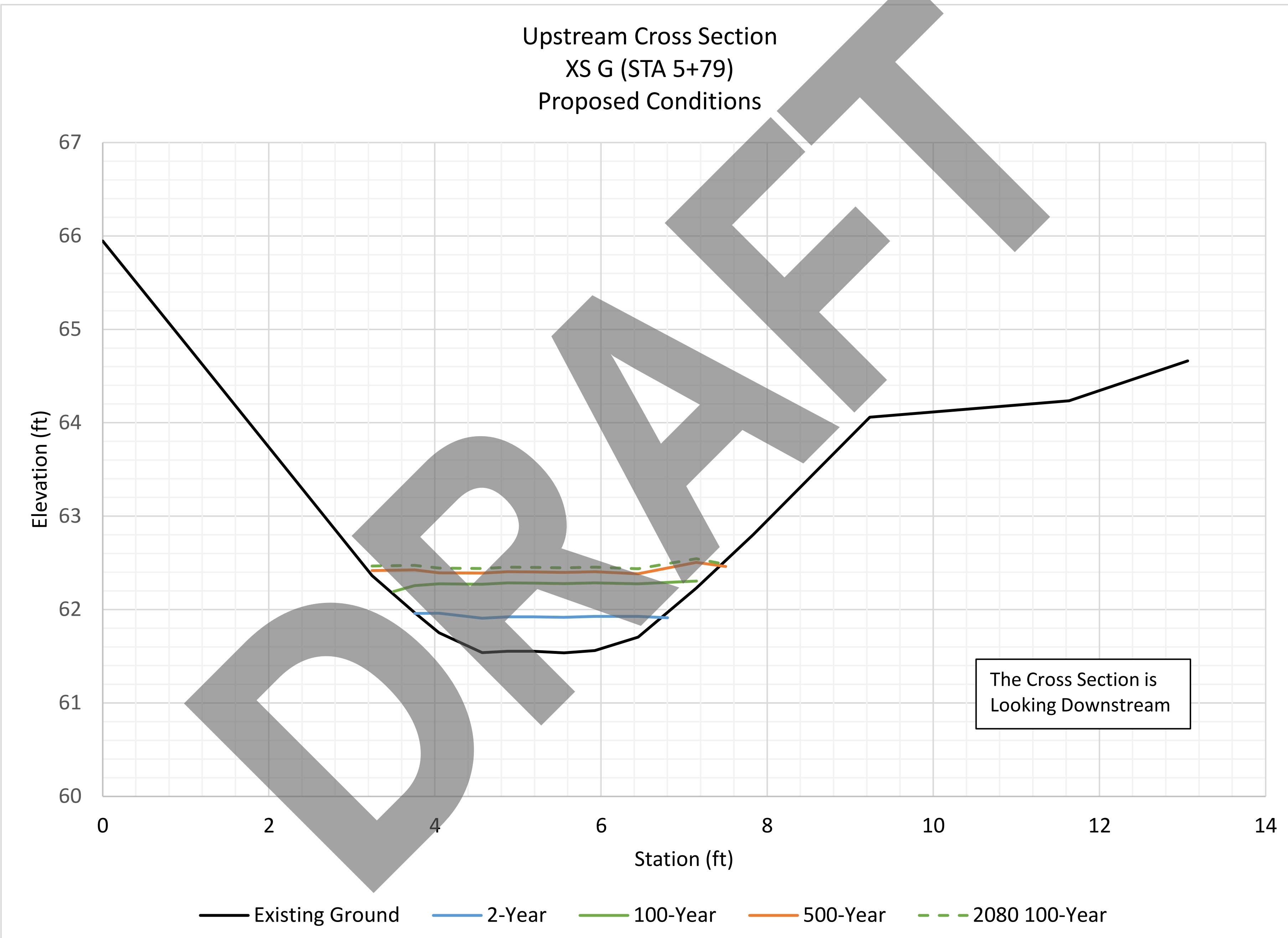
Upstream Cross Section
XS F (STA 55+52)
Existing Conditions
63
62
61
60
59
Elevation (ft)
0
1
2
3
4
5
6
7
8
9
10
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
DRAFT



Upstream Cross Section
XS F (STA 5+51)
Proposed Conditions
Elevation (ft)
63
62
61
60
59
0
1
2
3
4
5
6
7
8
9
10
Station (ft)
The Cross Section is Looking Downstream
Proposed Grade
2-Year
100-Year
500-Year
2080 100-Year
DRAFT



Upstream Cross Section
XS G (STA 55+80)
Existing Conditions
Elevation (ft)
67
66
65
64
63
62
61
60
0
2
4
6
8
10
12
14
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
DRAFT



Upstream Cross Section
XS G (STA 5+79)
Proposed Conditions
DRAFT
67
66
65
64
63
62
61
60
Elevation (ft)
0
2
4
6
8
10
12
14
Station (ft)
The Cross Section is Looking Downstream
Existing Ground
2-Year
100-Year
500-Year
2080 100-Year

DEPTH

N

0 20 40 Feet

HDR

Washington State Department of Transportation

EXISTING CONDITIONS 2-YEAR

UNT TO HOOD CANAL

MP 59.55

DEPTH

N

0 20 40 Feet

EXISTING CONDITIONS 100-YEAR

UNT TO HOOD CANAL

MP 59.55

HDR

Washington State Department of Transportation

DEPTH

N

0 20 40 Feet

HDR

Washington State Department of Transportation

EXISTING CONDITIONS 500-YEAR

UNT TO HOOD CANAL

MP 59.55

DEPTH

N

0 20 40 Feet

HDR Washington State Department of Transportation

PROPOSED CONDITIONS 2-YEAR

UNT TO HOOD CANAL
MP 59.55

DEPTH

N

0 20 40 Feet

HDR

Washington State
Department of Transportation

PROPOSED CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.55

DEPTH

0 20 40 Feet

HDR

Washington State Department of Transportation

PROPOSED CONDITIONS 500-YEAR

UNT TO HOOD CANAL
MP 59.55

DEPTH

0 20 40 Feet

N

PROPOSED CONDITIONS 100-YEAR 2080

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL
MP 59.55

SHEAR

0 20 40 Feet

EXISTING CONDITIONS 2-YEAR

UNT TO HOOD CANAL
MP 59.55

HDR
Washington State Department of Transportation

PATH: D:\WSDOT_PHD\MAP\59.55\WDOT_PRO_FIGURES.APRX - USER: IBRENNER - DATE: 9/9/2022

PRELIMINARY HYDRAULIC DESIGN

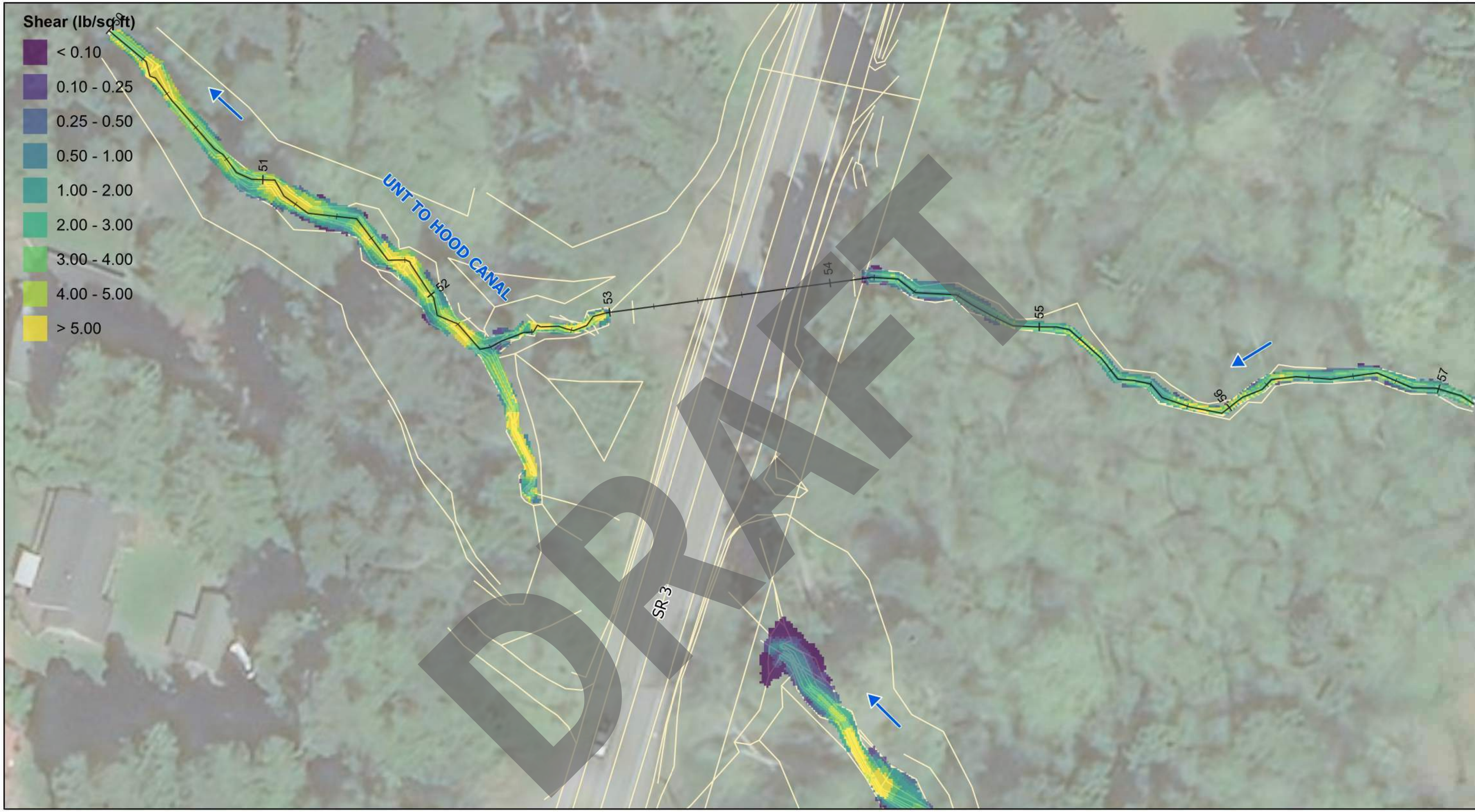
SHEAR

0 20 40 Feet

EXISTING CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.55

HDR Washington State Department of Transportation



SHEAR

N

0 20 40 Feet

HDR

Washington State Department of Transportation

EXISTING CONDITIONS 500-YEAR

UNT TO HOOD CANAL

MP 59.55

SHEAR

0 20 40 Feet

HDR Washington State Department of Transportation

PROPOSED CONDITIONS 2-YEAR

UNT TO HOOD CANAL
MP 59.55

SHEAR

0 20 40 Feet

HDR

Washington State Department of Transportation

PROPOSED CONDITIONS 100-YEAR

UNT TO HOOD CANAL

MP 59.55

SHEAR

N

0 20 40 Feet

HDR Washington State Department of Transportation

PROPOSED CONDITIONS 500-YEAR

UNT TO HOOD CANAL
MP 59.55

PATH: D:\WSDOT_PHD\MAP\59.55\WDOT_PRO_FIGURES.APRX - USER: IBRENNER - DATE: 9/9/2022

PRELIMINARY HYDRAULIC DESIGN

SHEAR

0 20 40 Feet

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PROPOSED CONDITIONS 100-YEAR 2080

UNT TO HOOD CANAL
MP 59.55

VELOCITY

0 20 40 Feet

HDR

Washington State Department of Transportation

EXISTING CONDITIONS 2-YEAR

UNT TO HOOD CANAL
MP 59.55

VELOCITY

0 20 40 Feet

HDR Washington State Department of Transportation

EXISTING CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.55

PATH: D:\WSDOT_PHD\MAP\59.55\WDOT_PRO_FIGURES.APRX - USER: IBRENNER - DATE: 9/9/2022

PRELIMINARY HYDRAULIC DESIGN

VELOCITY

N

0 20 40 Feet

EXISTING CONDITIONS 500-YEAR

UNT TO HOOD CANAL

MP 59.55

HDR

Washington State Department of Transportation

VELOCITY

N

0 20 40 Feet

HDR

Washington State Department of Transportation

PROPOSED CONDITIONS 2-YEAR

UNT TO HOOD CANAL

MP 59.55

PATH: C:\USERS\IBRENNER\ONEDRIVE - HDR, INC\EXTERNAL\D\WSDOT_PHD\MAP\59.55\WDOT_PRO_FIGURES.APRX - USER: IBRENNER - DATE: 9/12/2022

PRELIMINARY HYDRAULIC DESIGN

VELOCITY

N

0 20 40 Feet

PROPOSED CONDITIONS 100-YEAR

Washington State Department of Transportation

UNT TO HOOD CANAL

MP 59.55

VELOCITY

N

0 20 40 Feet

HDR

Washington State Department of Transportation

PROPOSED CONDITIONS 500-YEAR

UNT TO HOOD CANAL

MP 59.55

PATH: C:\USERS\IBRENNER\ONEDRIVE - HDR, INC\EXTERNAL\WSDOT_PHD\MAP\59.55\WDOT_PRO_FIGURES.APRX - USER: IBRENNER - DATE: 9/12/2022

PRELIMINARY HYDRAULIC DESIGN

VELOCITY

N

0 20 40 Feet

HDR

Washington State
Department of Transportation

PROPOSED CONDITIONS 100-YEAR 2080

UNT TO HOOD CANAL
MP 59.55

PATH: C:\USERS\IBRENNER\ONEDRIVE - HDR, INC\EXTERNAL\WSDOT_PHD\MAP\59.55\WDOT_PRO_FIGURES.APRX - USER: IBRENNER - DATE: 9/12/2022

PRELIMINARY HYDRAULIC DESIGN

WATER SURFACE ELEVATION

N

0 20 40 Feet

EXISTING CONDITIONS 2-YEAR

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL

MP 59.55

PATH: D:\WSDOT_PHD\MAP\59.55\WDOT_PRO_FIGURES.APRX - USER: IBRENNER - DATE: 9/9/2022

PRELIMINARY HYDRAULIC DESIGN

WATER SURFACE ELEVATION

N

0 20 40 Feet

HDR

Washington State Department of Transportation

EXISTING CONDITIONS 100-YEAR

UNT TO HOOD CANAL
MP 59.55

WATER SURFACE ELEVATION

N

0 20 40 Feet

HDR Washington State Department of Transportation

EXISTING CONDITIONS 500-YEAR

UNT TO HOOD CANAL

MP 59.55

WATER SURFACE ELEVATION

N

0 20 40 Feet

PROPOSED CONDITIONS 2-YEAR

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL

MP 59.55

WATER SURFACE ELEVATION

0 20 40 Feet

PROPOSED CONDITIONS 100-YEAR

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL
MP 59.55

PATH: D:\WSDOT_PHD\MAP\59.55\WDOT_PRO_FIGURES.APRX - USER: IBRENNER - DATE: 9/9/2022

PRELIMINARY HYDRAULIC DESIGN

WATER SURFACE ELEVATION

N

0 20 40 Feet

PROPOSED CONDITIONS 500-YEAR

HDR

Washington State Department of Transportation

UNT TO HOOD CANAL

MP 59.55

WATER SURFACE ELEVATION

N

0 20 40 Feet

HDR | Washington State Department of Transportation

PROPOSED CONDITIONS 100-YEAR 2080

UNT TO HOOD CANAL

MP 59.55

PATH: D:\WSDOT_PHD\MAP\59.55\WDOT_PRO_FIGURES.APRX - USER: IBRENNER - DATE: 9/9/2022

PRELIMINARY HYDRAULIC DESIGN

Appendix I: SRH-2D Model Stability and Continuity

PLAN VIEW MONITORING LOCATIONS

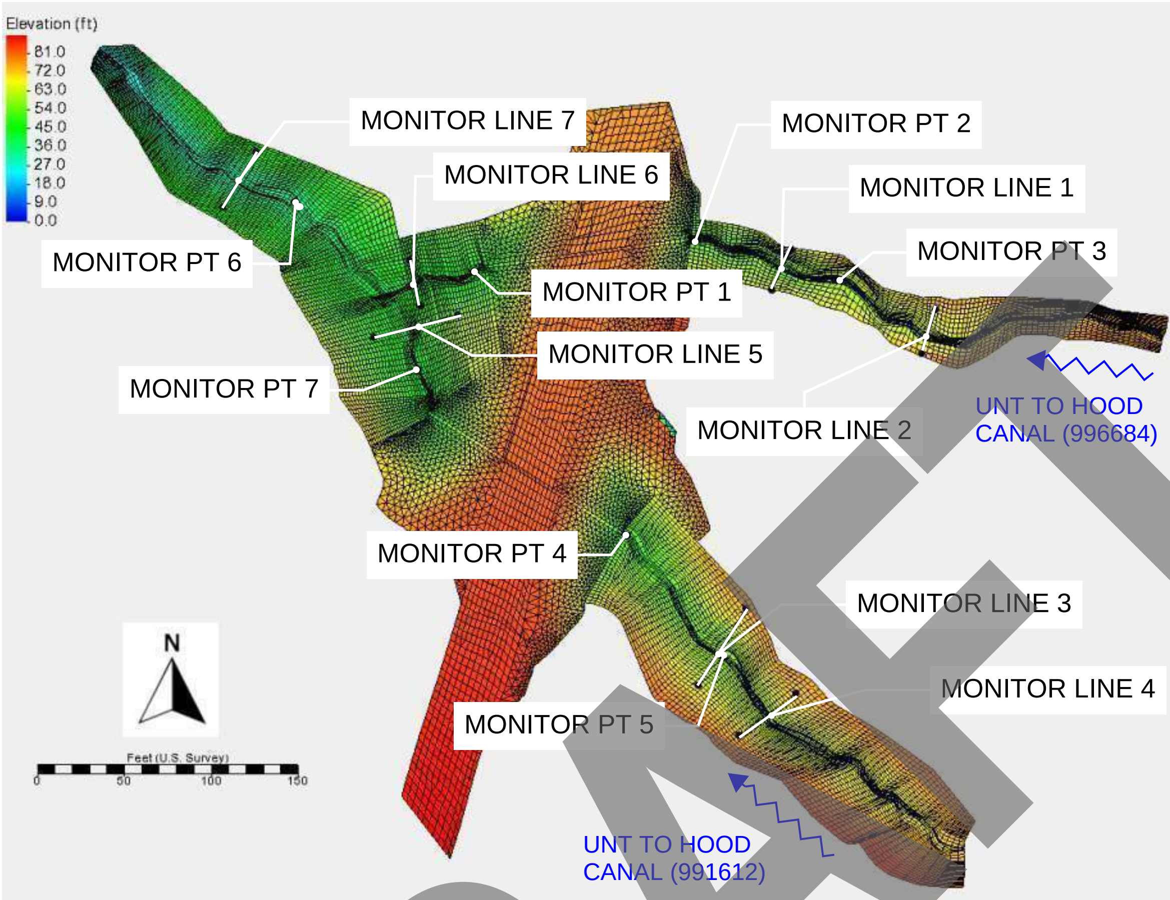


FIGURE 1. EXISTING CONDITIONS MONITORING LOCATIONS

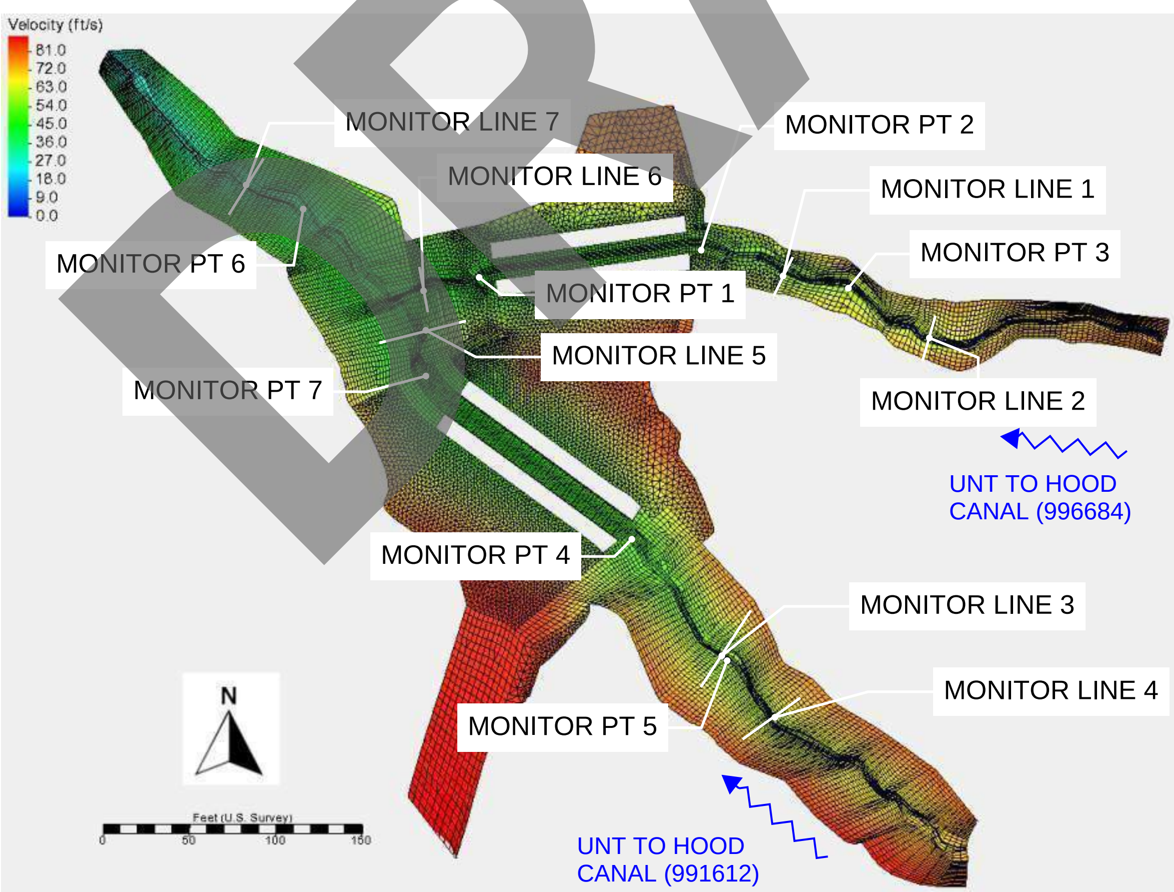
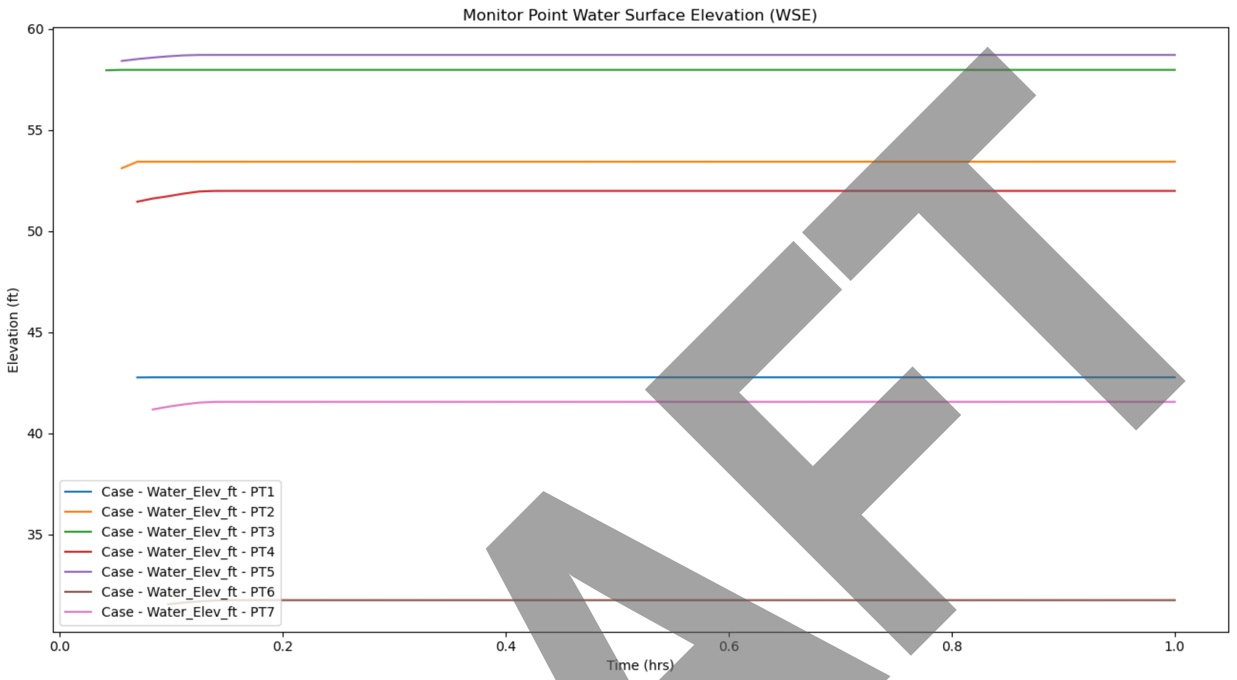


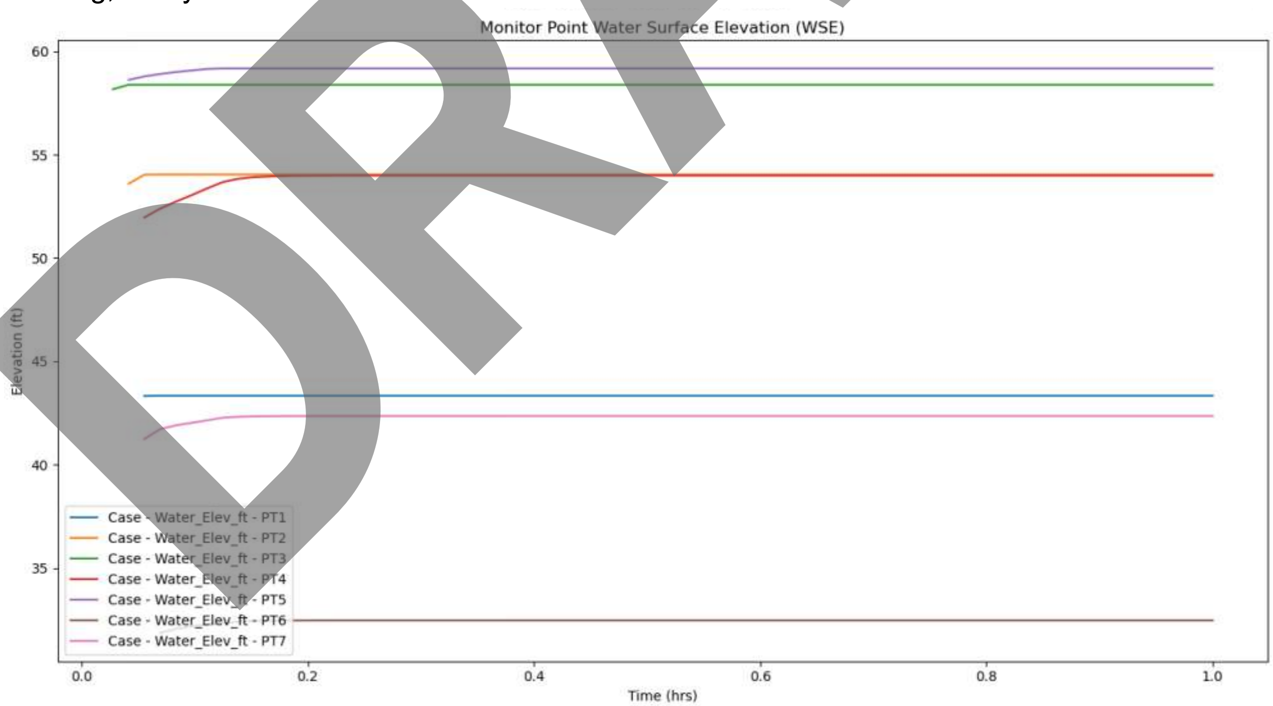
FIGURE 2. PROPOSED CONDITIONS MONITORING LOCATIONS

Monitoring Point WSE Plots:

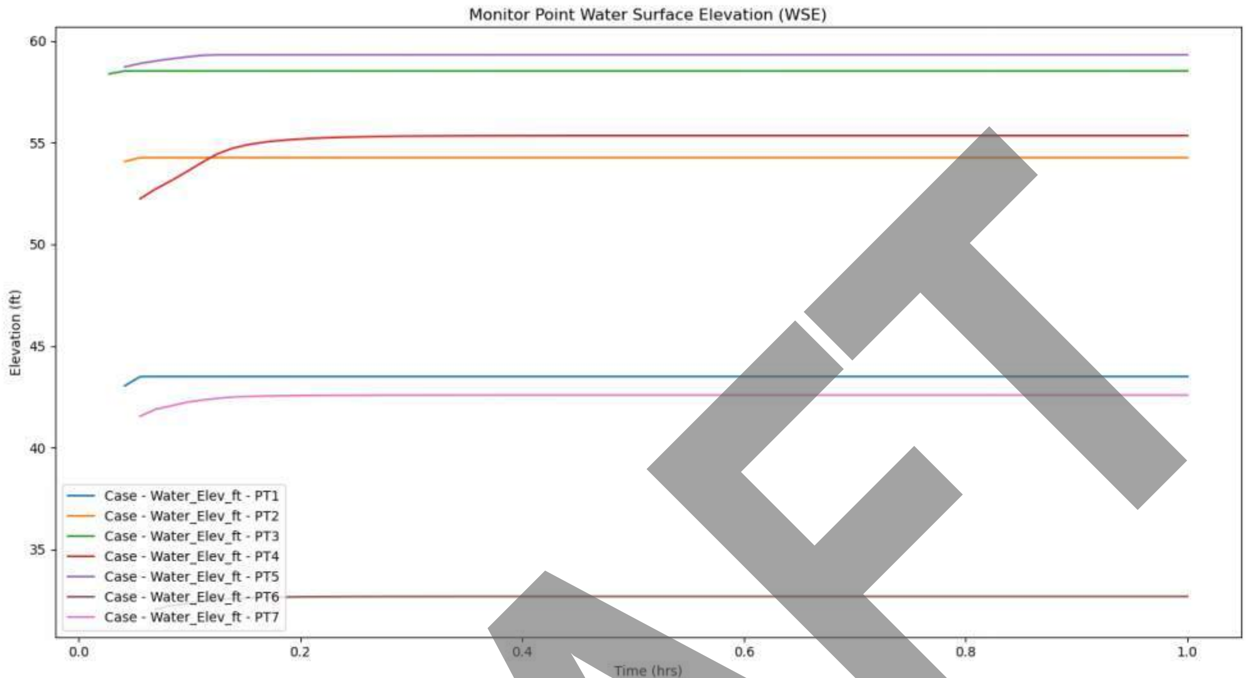
Existing, 2-year:



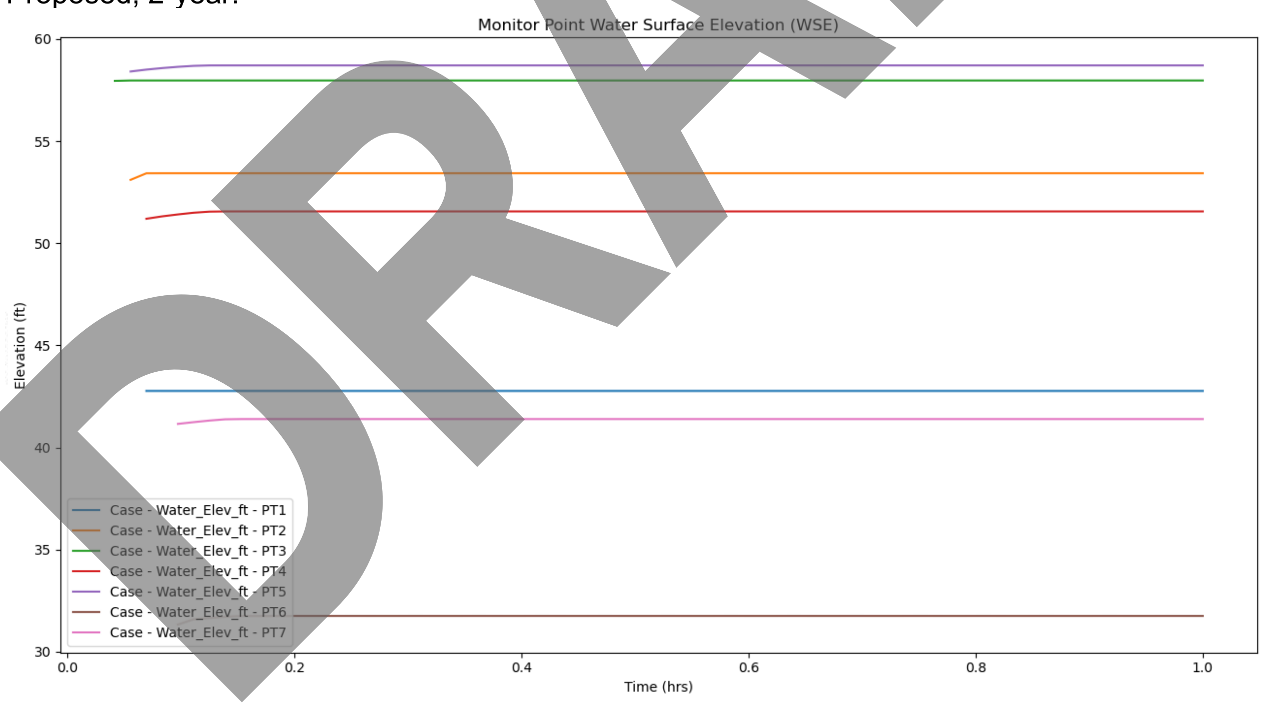
Existing, 100-year:



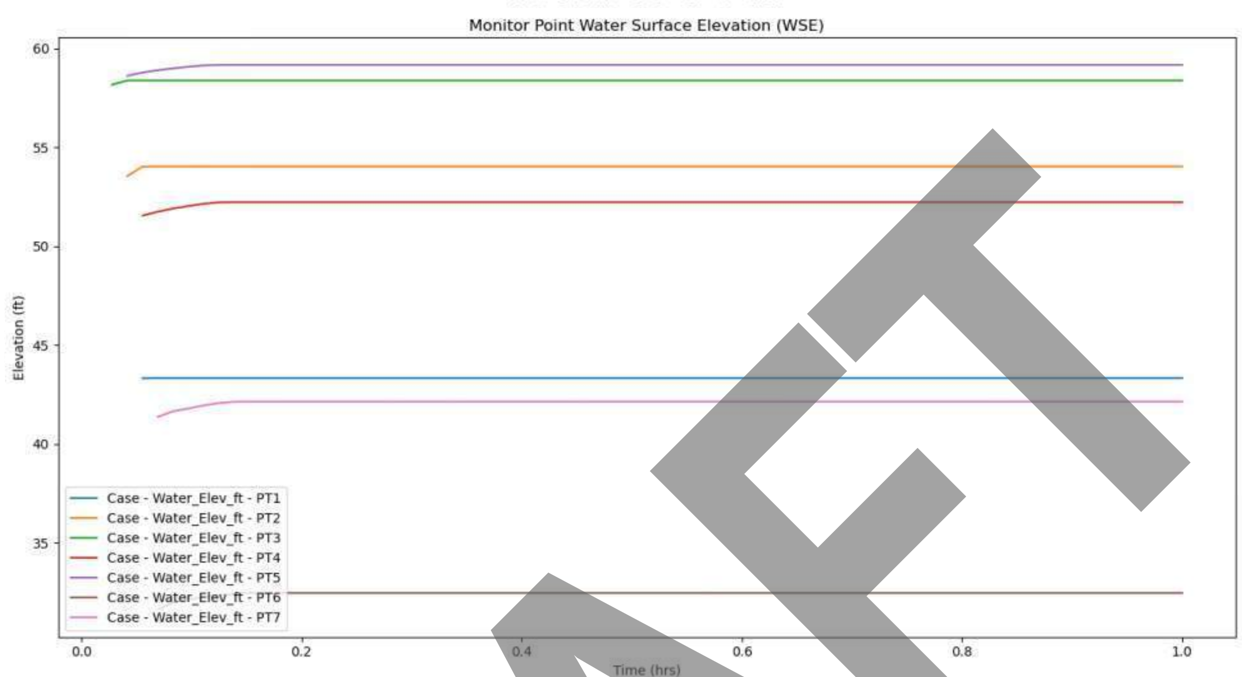
Existing, 500-year:



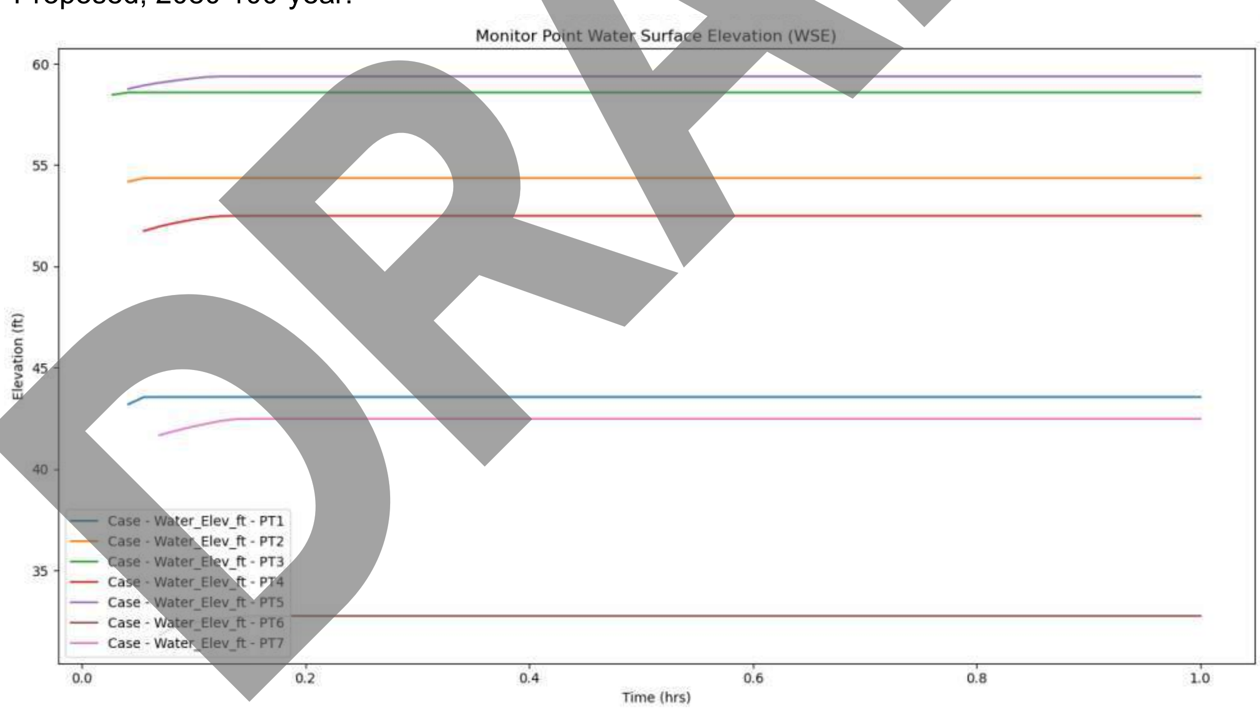
Proposed, 2-year:



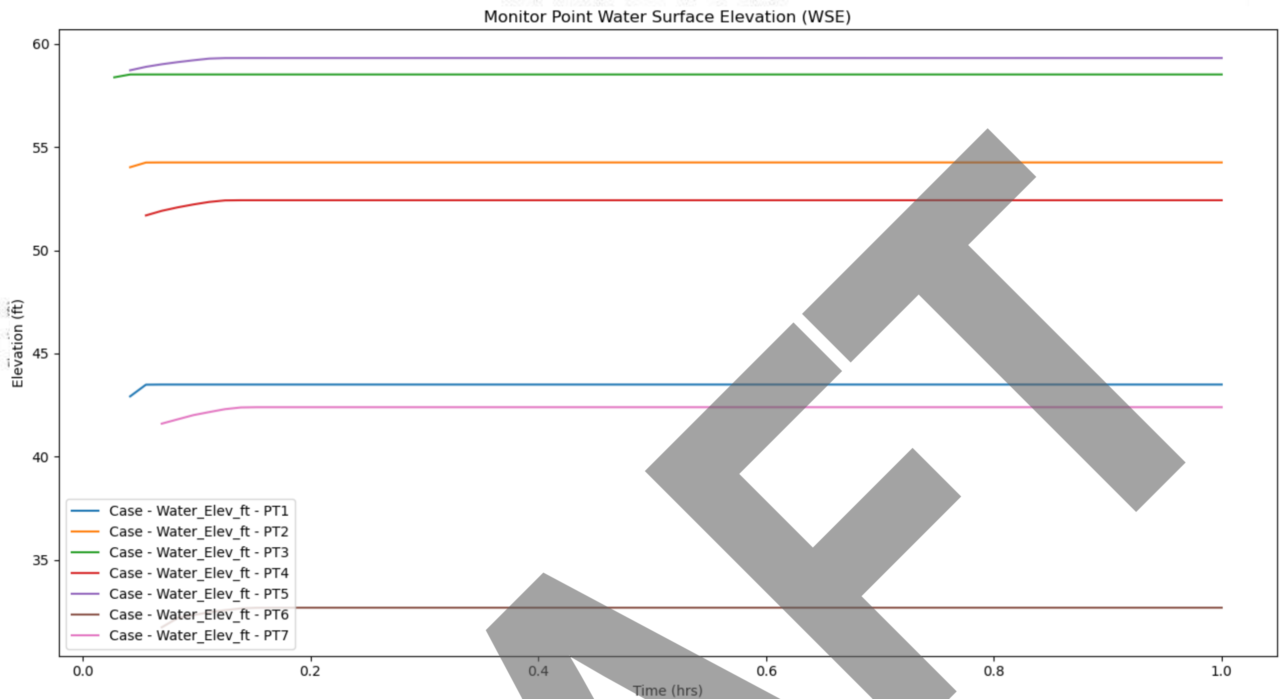
Proposed, 100-year:



Proposed, 2080 100-year:

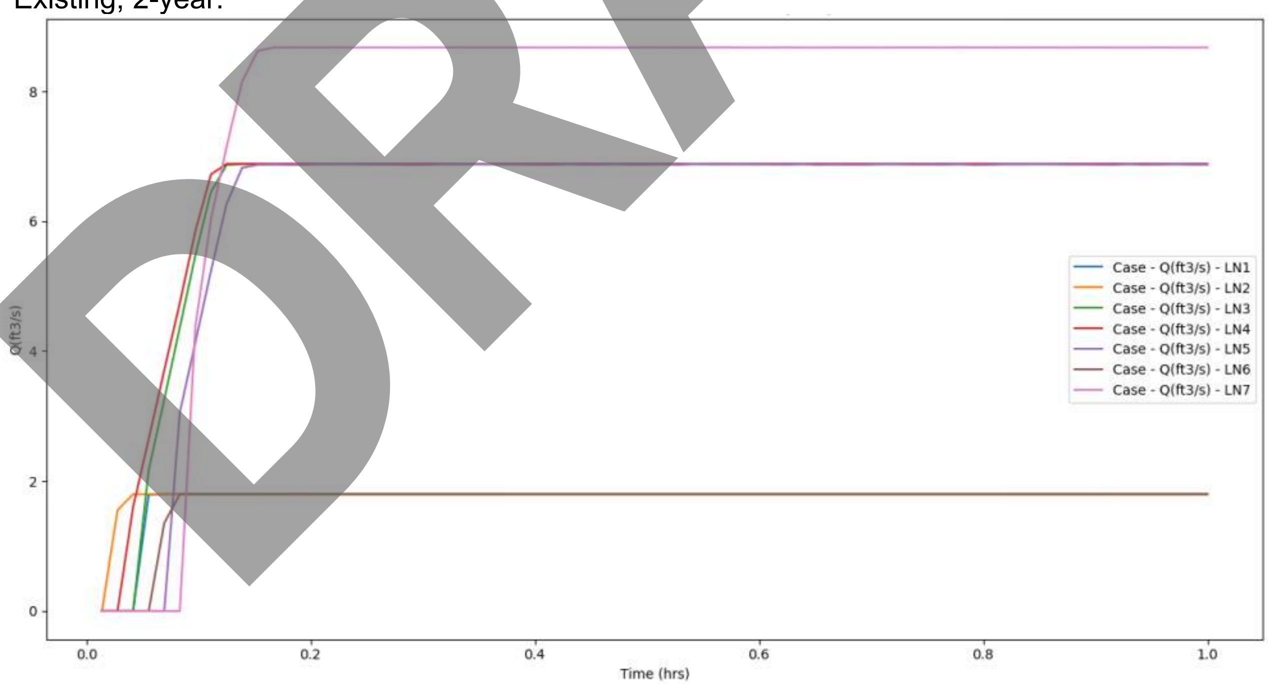


Proposed, 500-year:



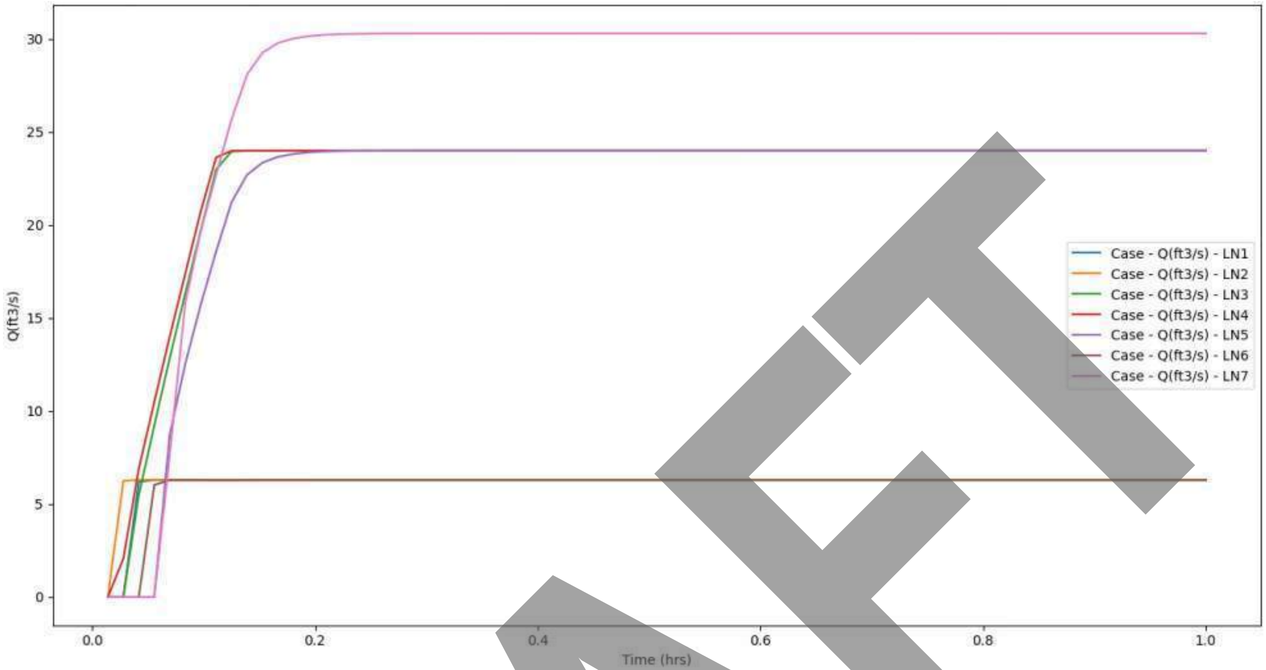
Monitoring Line Flow Plots:

Existing, 2-year:

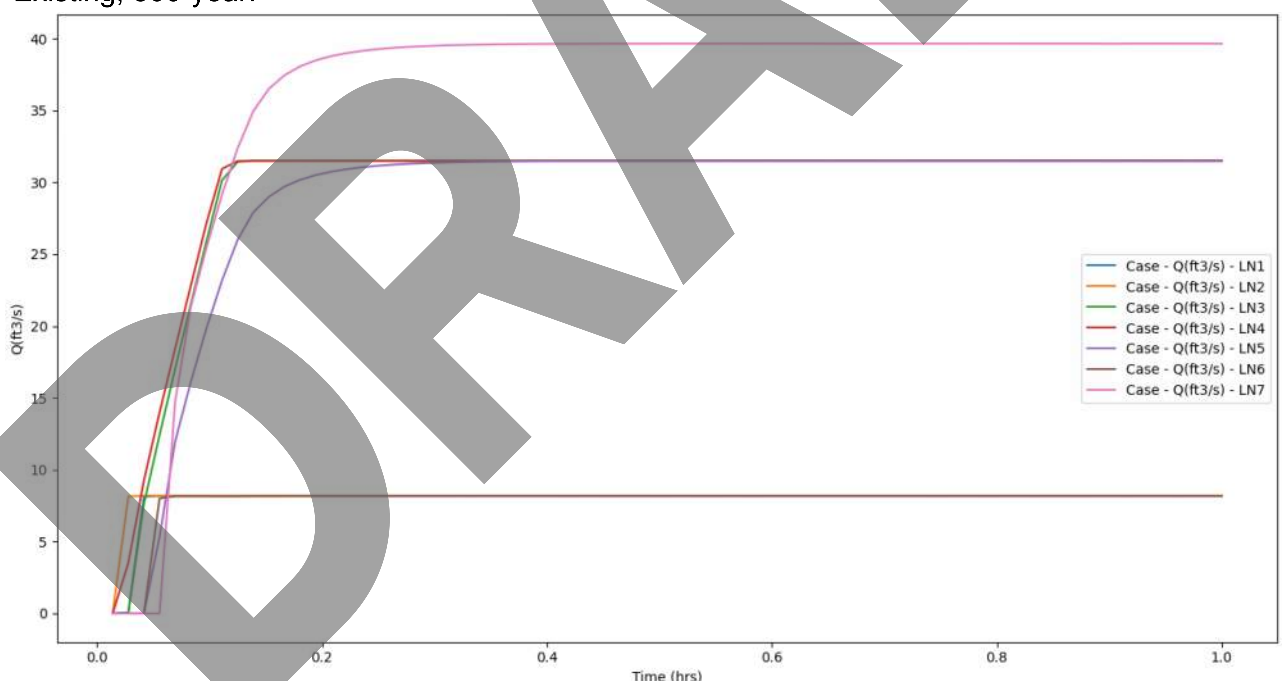


DRAFT

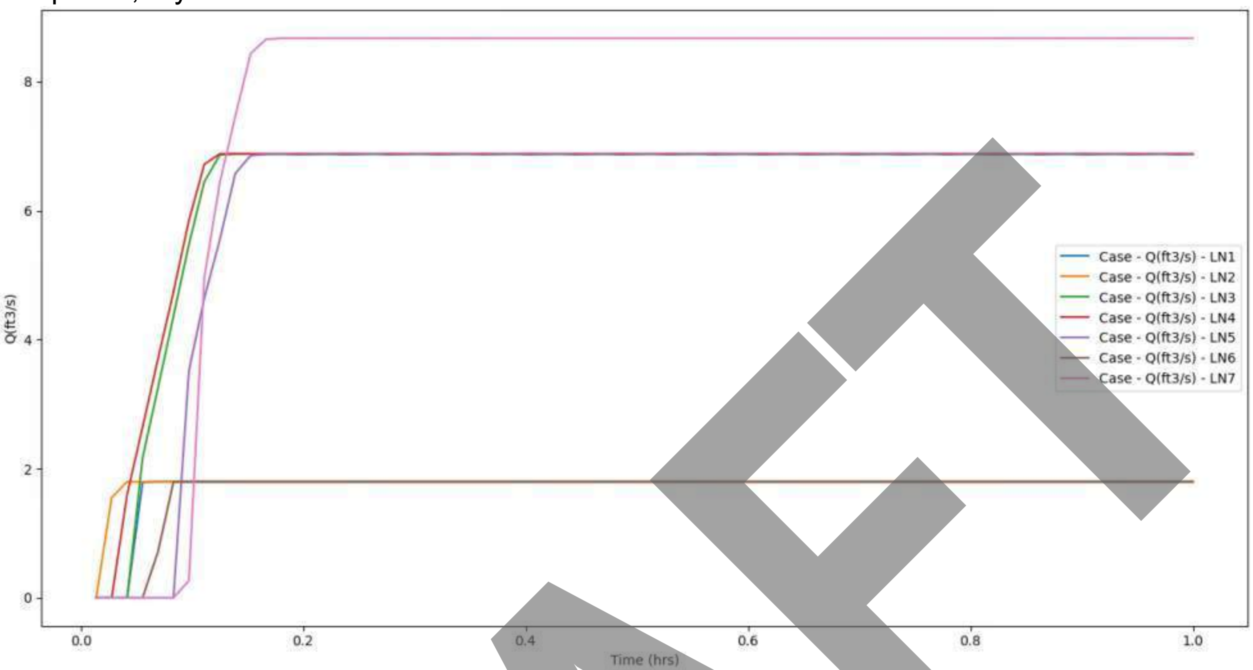
Existing, 100-year:



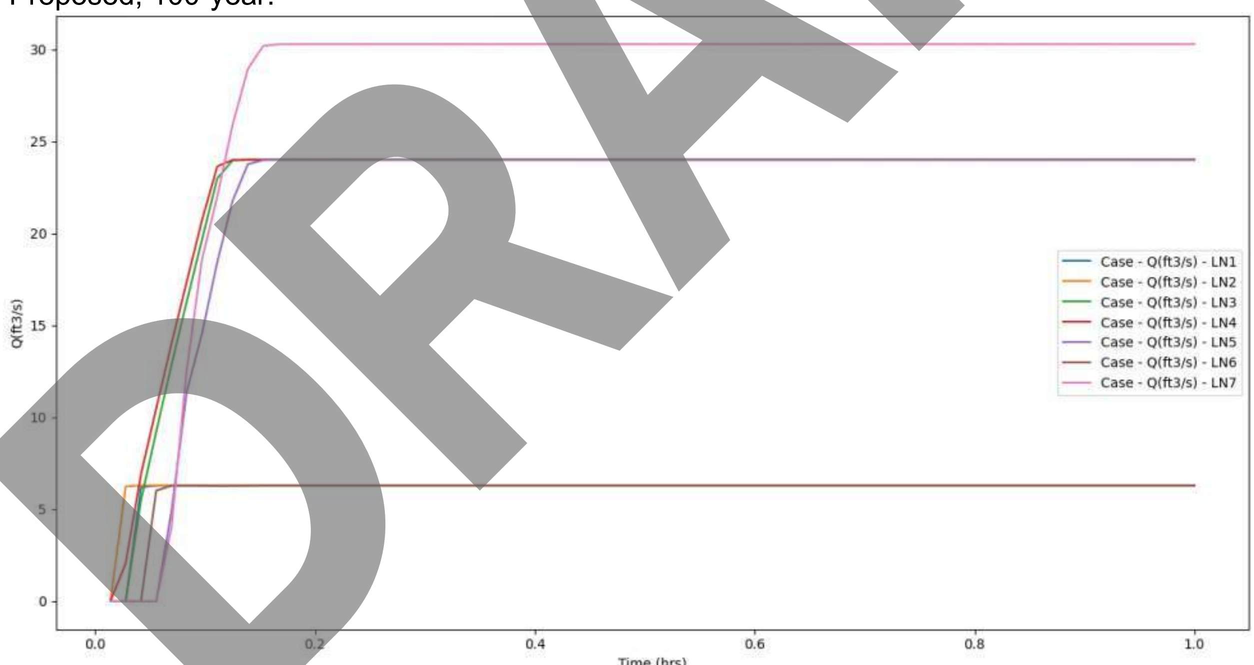
Existing, 500-year:



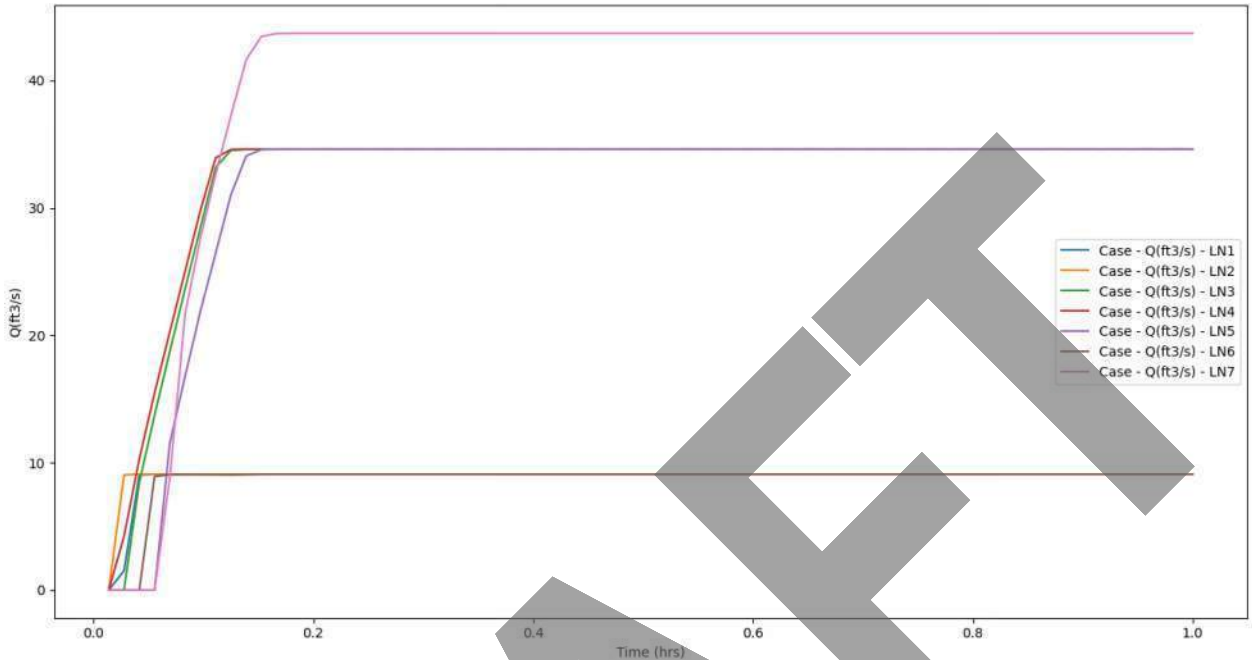
Proposed, 2-year:



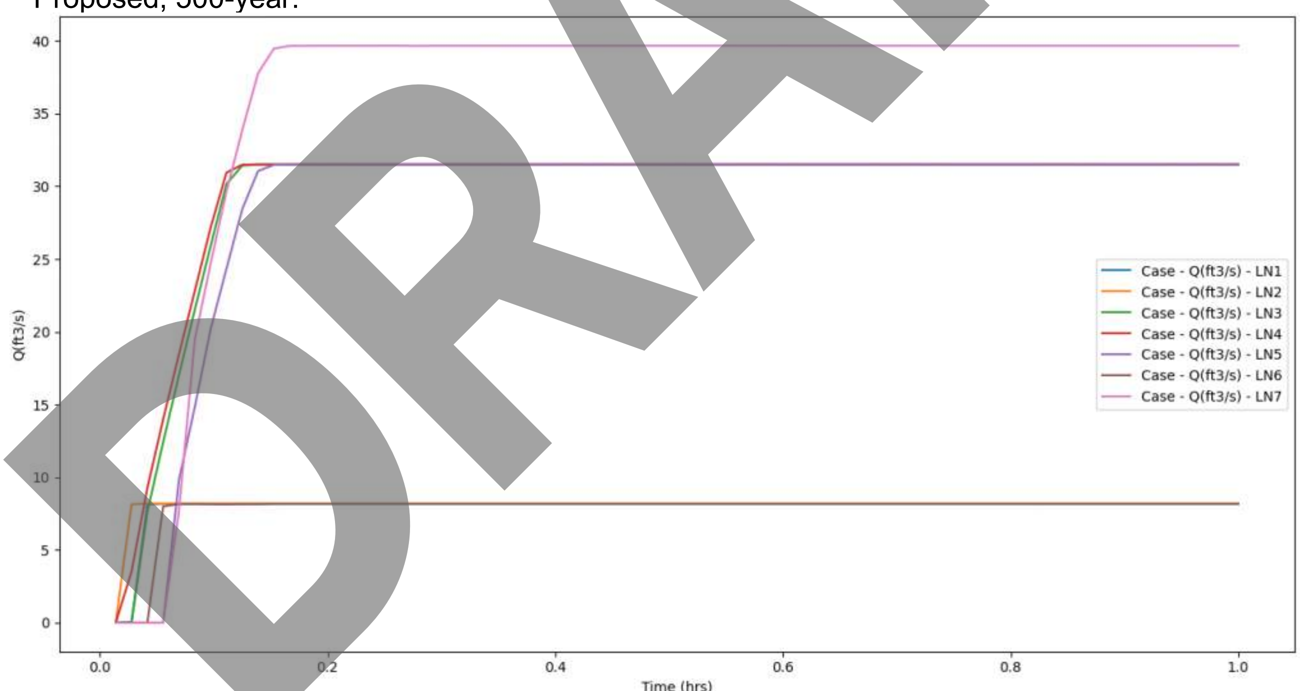
Proposed, 100-year:



Proposed, 2080 100-year:



Proposed, 500-year:



Appendix J: Reach Assessment (N/A)

Appendix K: Scour Calculations

Project:	UNT to Hood Canal	Computed:	RIA	Date:	
Subject:	Scour Analysis	Checked:	TM	Date:	
Task:	Bend Scour	Page:	1	of:	1
Job #:		No:			

Computation of Bend Scour

Variables and Equations

References: ***FHWA. 2009. Hydraulic Engineering Circular No. 23 Third Edition, Volume 1 Chapter 4***
NRCS. 2007. National Engineering Handbook Part 654. TS 14B. Scour Calculations.

Maynord's method for estimating scour depth at bend:

$$\frac{D_{mxb}}{D_{mnc}} = 1.8 - 0.051\left(\frac{R_c}{W}\right) + 0.0084\left(\frac{W}{D_{mnc}}\right) \quad (4.5)$$

R_c	ft	Centerline radius of the bend
W	ft	Width upstream of bend
D_{mxb}	ft	Maximum water depth in the bend
D_{mnc}	ft	Average water depth in the crossing upstream of the bend. Cross sectional area/width
y_s	ft	Scour depth below proposed thalweg
y_0	ft	Thalweg depth at bend prior to bend scour occurring

$y_s = D_{mxb} - D_{mnc}$ ft

Per HEC-23, for channels with $R_c/W < 1.5$ or $W/D_{mnc} < 20$, the scour depth calculations should use $R_c/W = 1.5$ and $W/D_{mnc} = 20$, respectively. Equation only valid when no to minimal overbank flow.

Computation of Bend Scour

	2-year	100-year	2080 100-year	500-year	
Rc	33.1	33.1	33.1	33.1	ft
W	3.1	3.1	3.1	3.1	ft
Dmnc	0.3	0.7	0.9	0.8	ft
y_0	0.3	0.7	0.8	0.8	ft
R_c/W =	10.5	10.5	10.5	10.5	
W/Dmnc =	10.5	4.6	3.7	3.9	

Notes (results pulled from main channel only)
STA 4+57 used for data inputs
Approach section main channel width measured in SMS
Avg water depth taken US at approach section
Bend section main channel average depth
No data points taken at fringe nodes of cross sections

If R_c/W is less than 1.5/ greater than 10 or width to depth ratio is less than 20/ greater than 125, the scour depth for Rc/W=1.5 and W/Dmnc=20 should be used.

	2-year	100-year	2080 100-year	500-year	
R_c/W =	1.5	1.5	1.5	1.5	
W/Dmnc =	20.0	20.0	20.0	20.0	
Dmxb =	0.6	1.3	1.6	1.5	ft
FOS =	1.08	1.08	1.08	1.08	Applied Factor of Safety to Dmxb
y_s =	**0.2**	**0.5**	**0.7**	**0.7**	**ft**

Hydraulic Analysis Report

Project Data

Project Title: SR 3 MP 59.55 Scour

Designer: Rachel Ainslie

Project Date: Friday, June 10, 2022

Project Units: U.S. Customary Units

Notes:

Bridge Scour Analysis:Bridge Scour Analysis

Notes:

Scenario: Proposed59.55_100yr_2080 (SRH-2D)

Long Term Degradation

User-Specified Scour Depth

Long Term Degradation (LTD) 4.00 ft

Minimum Channel Elevation with LTD 44.12 ft

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Live Bed Contraction Scour Depth 0.19 ft

Applied Contraction Scour Elevation with LTD 0.19 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.00 ft

Total Scour at Abutment 0.00 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.00 ft

Total Scour at Abutment 0.00 ft

Long Term Details

Long-Term Degradation

Computation Type:

Input Parameters

Shield's Parameter: 0.0300

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.86 ft

D50: 10.058400 mm

Average Velocity Upstream: 2.23 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 3.49 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 7.75 cfs

Bottom Width in Contracted Section: 2.99 ft

Depth Prior to Scour in Contracted Section: 0.84 ft

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 7.75 cfs

Flow Upstream that is Transporting Sediment: 8.48 cfs

Width in Contracted Section: 2.99 ft

Width Upstream that is Transporting Sediment: 4.44 ft

Depth Prior to Scour in Contracted Section: 0.84 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 12.573000 mm

Average Depth in Contracted Section after Scour: 0.70 ft

Scour Depth: -0.14 ft

Results of Live Bed Method

Shear Velocity: 1.36 ft/s

Fall Velocity: 1.44 ft/s

Average Depth in Contracted Section after Scour: 1.02 ft

Scour Depth for Live Bed: 0.19 ft

Shear Applied to Bed by Live-Bed Scour: 0.0679 lb/ft^2

Shear Required for Movement of D50 Particle: 0.1320 lb/ft^2

Recommendations

Recommended Scour Depth: -0.14 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.50 ft

D50: 0.000000 mm

Average Velocity Upstream: 0.00 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 0.69 cfs

Flow Upstream that is Transporting Sediment: 0.00 cfs

Width in Contracted Section: 0.77 ft

Width Upstream that is Transporting Sediment: 0.74 ft

Depth Prior to Scour in Contracted Section: 0.36 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Right Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.16 ft

D50: 0.000000 mm

Average Velocity Upstream: 0.00 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 0.28 cfs

Flow Upstream that is Transporting Sediment: 0.00 cfs

Width in Contracted Section: 0.74 ft

Width Upstream that is Transporting Sediment: 1.01 ft

Depth Prior to Scour in Contracted Section: 0.36 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Spill-through abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 0.00 cfs

Unit Discharge in the Constricted Area (q2): 0.00 cfs/ft

D50: 0.000000 mm

Upstream Flow Depth: 0.00 ft

Flow Depth Prior to Scour: 0.00 ft

Result Parameters

q2/q1: 0.00

Average Velocity Upstream: 0.00 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 0.00 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: -nan(ind)

Scour Condition: b (overbank)

Amplification Factor: 0.00

Flow Depth including Contraction Scour: 0.00 ft

Maximum Flow Depth including Abutment Scour: 0.00 ft

Scour Hole Depth from NCHRP Method: 0.00 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Spill-through abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 0.00 cfs

Unit Discharge in the Constricted Area (q2): 0.00 cfs/ft

D50: 0.000000 mm

Upstream Flow Depth: 0.00 ft

Flow Depth Prior to Scour: 0.00 ft

Result Parameters

q2/q1: 0.00

Average Velocity Upstream: 0.00 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 0.00 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: -nan(ind)

Scour Condition: b (overbank)

Amplification Factor: 0.00

Flow Depth including Contraction Scour: 0.00 ft

Maximum Flow Depth including Abutment Scour: 0.00 ft

Scour Hole Depth from NCHRP Method: 0.00 ft

Scenario: Proposed59.55_2yr (SRH-2D)

Long Term Degradation

User-Specified Scour Depth

Long Term Degradation (LTD) 4.00 ft

Minimum Channel Elevation with LTD 44.12 ft

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Live Bed Contraction Scour Depth 0.19 ft

Applied Contraction Scour Elevation with LTD 0.19 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.00 ft

Total Scour at Abutment 0.00 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.00 ft

Total Scour at Abutment 0.00 ft

Long Term Details

Long-Term Degradation

Computation Type:

Input Parameters

Shield's Parameter: 0.0300

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.86 ft

D50: 10.058400 mm

Average Velocity Upstream: 2.23 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 3.49 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 7.75 cfs

Bottom Width in Contracted Section: 2.99 ft

Depth Prior to Scour in Contracted Section: 0.84 ft

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 7.75 cfs

Flow Upstream that is Transporting Sediment: 8.48 cfs

Width in Contracted Section: 2.99 ft

Width Upstream that is Transporting Sediment: 4.44 ft

Depth Prior to Scour in Contracted Section: 0.84 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 12.573000 mm

Average Depth in Contracted Section after Scour: 0.70 ft

Scour Depth: -0.14 ft

Results of Live Bed Method

Shear Velocity: 1.36 ft/s

Fall Velocity: 1.44 ft/s

Average Depth in Contracted Section after Scour: 1.02 ft

Scour Depth for Live Bed: 0.19 ft

Shear Applied to Bed by Live-Bed Scour: 0.0679 lb/ft^2

Shear Required for Movement of D50 Particle: 0.1320 lb/ft^2

Recommendations

Recommended Scour Depth: -0.14 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.50 ft

D50: 0.000000 mm

Average Velocity Upstream: 0.00 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 0.69 cfs

Flow Upstream that is Transporting Sediment: 0.00 cfs

Width in Contracted Section: 0.77 ft

Width Upstream that is Transporting Sediment: 0.74 ft

Depth Prior to Scour in Contracted Section: 0.36 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Right Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.16 ft

D50: 0.000000 mm

Average Velocity Upstream: 0.00 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 0.28 cfs

Flow Upstream that is Transporting Sediment: 0.00 cfs

Width in Contracted Section: 0.74 ft

Width Upstream that is Transporting Sediment: 1.01 ft

Depth Prior to Scour in Contracted Section: 0.36 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Spill-through abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 0.00 cfs

Unit Discharge in the Constricted Area (q2): 0.00 cfs/ft

D50: 0.000000 mm

Upstream Flow Depth: 0.00 ft

Flow Depth Prior to Scour: 0.00 ft

Result Parameters

q2/q1: 0.00

Average Velocity Upstream: 0.00 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 0.00 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: -nan(ind)

Scour Condition: b (overbank)

Amplification Factor: 0.00

Flow Depth including Contraction Scour: 0.00 ft

Maximum Flow Depth including Abutment Scour: 0.00 ft

Scour Hole Depth from NCHRP Method: 0.00 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Spill-through abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 0.00 cfs

Unit Discharge in the Constricted Area (q2): 0.00 cfs/ft

D50: 0.000000 mm

Upstream Flow Depth: 0.00 ft

Flow Depth Prior to Scour: 0.00 ft

Result Parameters

q2/q1: 0.00

Average Velocity Upstream: 0.00 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 0.00 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: -nan(ind)

Scour Condition: b (overbank)

Amplification Factor: 0.00

Flow Depth including Contraction Scour: 0.00 ft

Maximum Flow Depth including Abutment Scour: 0.00 ft

Scour Hole Depth from NCHRP Method: 0.00 ft

Scenario: Proposed59.55_100yr (SRH-2D)

Long Term Degradation

User-Specified Scour Depth

Long Term Degradation (LTD) 4.00 ft

Minimum Channel Elevation with LTD 44.12 ft

Contraction Scour Summary

Contraction & Long Term Scour is applied method due to greater scour.

Live Bed Contraction Scour Depth 0.19 ft

Applied Contraction Scour Elevation with LTD 0.19 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.00 ft

Total Scour at Abutment 0.00 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.00 ft

Total Scour at Abutment 0.00 ft

Long Term Details

Long-Term Degradation

Computation Type:

Input Parameters

Shield's Parameter: 0.0300

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.86 ft

D50: 10.058400 mm

Average Velocity Upstream: 2.23 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 3.49 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 7.75 cfs

Bottom Width in Contracted Section: 2.99 ft

Depth Prior to Scour in Contracted Section: 0.84 ft

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 7.75 cfs

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Shear Velocity: 1.36 ft/s

Fall Velocity: 1.44 ft/s

Average Depth in Contracted Section after Scour: 1.02 ft

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Shear Applied to Bed by Live-Bed Scour: 0.0679 lb/ft^2

Shear Required for Movement of D50 Particle: 0.1320 lb/ft^2

Recommendations

Recommended Scour Depth: -0.14 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.50 ft

D50: 0.000000 mm

Average Velocity Upstream: 0.00 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 0.69 cfs

Flow Upstream that is Transporting Sediment: 0.00 cfs

Width in Contracted Section: 0.77 ft

Width Upstream that is Transporting Sediment: 0.74 ft

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Unit Weight of Sediment: 165.00 lb/ft^3

Right Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.16 ft

D50: 0.000000 mm

Average Velocity Upstream: 0.00 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 0.28 cfs

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Depth Prior to Scour in Contracted Section: 0.36 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Spill-through abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 0.00 cfs

Unit Discharge in the Constricted Area (q2): 0.00 cfs/ft

D50: 0.000000 mm

Upstream Flow Depth: 0.00 ft

Flow Depth Prior to Scour: 0.00 ft

Result Parameters

q2/q1: 0.00

Average Velocity Upstream: 0.00 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 0.00 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: -nan(ind)

Scour Condition: b (overbank)

Amplification Factor: 0.00

Flow Depth including Contraction Scour: 0.00 ft

Maximum Flow Depth including Abutment Scour: 0.00 ft

Scour Hole Depth from NCHRP Method: 0.00 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Spill-through abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 0.00 cfs

Unit Discharge in the Constricted Area (q2): 0.00 cfs/ft

D50: 0.000000 mm

Upstream Flow Depth: 0.00 ft

Flow Depth Prior to Scour: 0.00 ft

Result Parameters

q2/q1: 0.00

Average Velocity Upstream: 0.00 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 0.00 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: -nan(ind)

Scour Condition: b (overbank)

Amplification Factor: 0.00

Flow Depth including Contraction Scour: 0.00 ft

Maximum Flow Depth including Abutment Scour: 0.00 ft

Scour Hole Depth from NCHRP Method: 0.00 ft

Scenario: Proposed59.55_500yr (SRH-2D)

Long Term Degradation

User-Specified Scour Depth

Long Term Degradation (LTD) 4.00 ft

Minimum Channel Elevation with LTD 44.12 ft

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Contraction & Long Term Scour is applied method due to greater scour.

Live Bed Contraction Scour Depth 0.19 ft

Applied Contraction Scour Elevation with LTD 0.19 ft

Local Scour at Abutments Summary

Left Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.00 ft

Total Scour at Abutment 0.00 ft

Right Abutment

Abutment Scour Method: NCHRP Method

Abutment Scour Depth 0.00 ft

Total Scour at Abutment 0.00 ft

Long Term Details

Long-Term Degradation

Computation Type:

Input Parameters

Shield's Parameter: 0.0300

Main Channel Contraction Scour

Computation Type: Clear-Water and Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.86 ft

D50: 10.058400 mm

Average Velocity Upstream: 2.23 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 3.49 ft/s

Contraction Scour Condition: Clear-Water

Live Bed and/or Clear Water Input Parameters

Flow in Contracted Section: 7.75 cfs

Bottom Width in Contracted Section: 2.99 ft

Depth Prior to Scour in Contracted Section: 0.84 ft

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 7.75 cfs

Flow Upstream that is Transporting Sediment: 8.48 cfs

Width in Contracted Section: 2.99 ft

Width Upstream that is Transporting Sediment: 4.44 ft

Depth Prior to Scour in Contracted Section: 0.84 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Results of Clear Water Method

Diameter of the smallest nontransportable particle in the bed material: 12.573000 mm

Average Depth in Contracted Section after Scour: 0.70 ft

Scour Depth: -0.14 ft

Results of Live Bed Method

Shear Velocity: 1.36 ft/s

Fall Velocity: 1.44 ft/s

Average Depth in Contracted Section after Scour: 1.02 ft

Scour Depth for Live Bed: 0.19 ft

Shear Applied to Bed by Live-Bed Scour: 0.0679 lb/ft^2

Shear Required for Movement of D50 Particle: 0.1320 lb/ft^2

Recommendations

Recommended Scour Depth: -0.14 ft

Left Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.50 ft

D50: 0.000000 mm

Average Velocity Upstream: 0.00 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 0.69 cfs

Flow Upstream that is Transporting Sediment: 0.00 cfs

Width in Contracted Section: 0.77 ft

Width Upstream that is Transporting Sediment: 0.74 ft

Depth Prior to Scour in Contracted Section: 0.36 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Right Bank Contraction Scour

Computation Type: Clear-Water or Live-Bed Scour

Input Parameters

Average Depth Upstream of Contraction: 0.16 ft

D50: 0.000000 mm

Average Velocity Upstream: 0.00 ft/s

Results of Scour Condition

Critical velocity above which bed material of size D and smaller will be transported: 0.00 ft/s

Contraction Scour Condition: Live-Bed

Live Bed and/or Clear Water Input Parameters

Temperature of Water: 60.00 ºF

Slope of Energy Grade Line at Approach Section: 0.0674 ft/ft

Flow in Contracted Section: 0.28 cfs

Flow Upstream that is Transporting Sediment: 0.00 cfs

Width in Contracted Section: 0.74 ft

Width Upstream that is Transporting Sediment: 1.01 ft

Depth Prior to Scour in Contracted Section: 0.36 ft

Unit Weight of Water: 62.40 lb/ft^3

Unit Weight of Sediment: 165.00 lb/ft^3

Left Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Spill-through abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 0.00 cfs

Unit Discharge in the Constricted Area (q2): 0.00 cfs/ft

D50: 0.000000 mm

Upstream Flow Depth: 0.00 ft

Flow Depth Prior to Scour: 0.00 ft

Result Parameters

q2/q1: 0.00

Average Velocity Upstream: 0.00 ft/s

Critical Velocity above which Bed Material of Size D and Smaller will be Transported: 0.00 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: -nan(ind)

Scour Condition: b (overbank)

Amplification Factor: 0.00

Flow Depth including Contraction Scour: 0.00 ft

Maximum Flow Depth including Abutment Scour: 0.00 ft

Scour Hole Depth from NCHRP Method: 0.00 ft

Right Abutment Details

Abutment Scour

Computation Type: NCHRP

Input Parameters

NCHRP Method

Abutment Type: Spill-through abutment

Angle of Embankment to Flow: 0.00 Degrees

Centerline Length of Embankment: 0.00 ft

Projected Length of Embankment: 0.00 ft

Width of Flood Plain: 0.00 ft

Unit Discharge, Upstream in Main Channel (q1): 0.00 cfs

Unit Discharge in the Constricted Area (q2): 0.00 cfs/ft

D50: 0.000000 mm

Upstream Flow Depth: 0.00 ft

Flow Depth Prior to Scour: 0.00 ft

Result Parameters

q2/q1: 0.00

Average Velocity Upstream: 0.00 ft/s

Critical Velocity above which Bed Materal of Size D and Smaller will be Transported: 0.00 ft/s

Scour Condition: Live Bed

Embankment Length/Floodplain Width Ratio: -nan(ind)

Scour Condition: b (overbank)

Amplification Factor: 0.00

Flow Depth including Contraction Scour: 0.00 ft

Maximum Flow Depth including Abutment Scour: 0.00 ft

Scour Hole Depth from NCHRP Method: 0.00 ft

Appendix L: Floodplain Analysis (FHD ONLY)

Appendix M: Scour Countermeasure Calculations (FHD ONLY)